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(54) **SEMICONDUCTOR FIN DEVICES AND  
METHOD OF FABRICATING THE  
SEMICONDUCTOR FIN DEVICES**

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H01L 27/0922; H01L 27/3248; H01L 29/435  
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257/E21.573, E21.577, E21.585, E21.632  
See application file for complete search history.

(56) **References Cited**

**U.S. PATENT DOCUMENTS**

7,282,450 B2 10/2007 Shue et al.  
7,344,942 B2 \* 3/2008 Korber ..... H01L 21/76229  
257/E21.548

(Continued)

**OTHER PUBLICATIONS**

R. Loo et al, Selective Area Growth of InP on On-Axis Si(001)  
Substrates with Low Antiphase Boundary Formation, Journal of The  
Electrochemical Society, 159 (3) (2012), pp. 260-265.

(Continued)

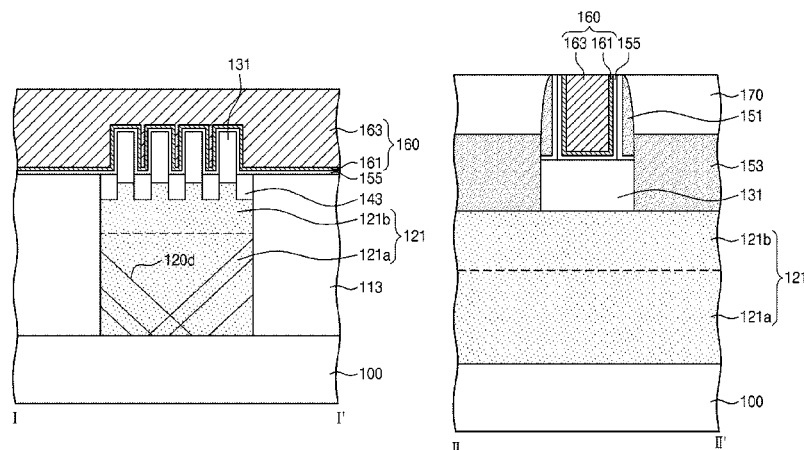
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(57) **ABSTRACT**

A semiconductor device includes a substrate, an insulating layer disposed on the substrate and having a trench exposing a surface portion of the substrate, and a channel-forming structure comprising crystalline semiconductor material. The channel-forming structure has a lower portion located in the trench and fins extending upright on the lower portion, where the fins are spaced from each other and are each narrower than an opening of the trench, and the lower portion of the channel forming structure has a higher crystal defect density than the fins of the channel forming structure.

**20 Claims, 23 Drawing Sheets**



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**H01L 29/36** (2006.01)  
**H01L 29/16** (2006.01)  
**H01L 29/20** (2006.01)
- 2012/0028444 A1 2/2012 Vellianitis  
2012/0168823 A1 7/2012 Luo et al.  
2012/0175675 A1 7/2012 Luo et al.  
2013/0115721 A1 5/2013 Clark

## OTHER PUBLICATIONS

- (56) **References Cited**

## U.S. PATENT DOCUMENTS

- 7,799,592 B2 9/2010 Lochtefeld  
7,977,706 B2 7/2011 Lochtefeld  
8,034,697 B2 10/2011 Fiorenza et al.  
8,173,551 B2 \* 5/2012 Bai et al. .... 438/758  
8,183,667 B2 5/2012 Park  
8,253,211 B2 8/2012 Cheng et al.  
8,274,097 B2 9/2012 Cheng  
8,304,805 B2 11/2012 Lochtefeld  
8,309,986 B2 \* 11/2012 Lochtefeld ..... H01L 29/66795  
257/190  
8,384,196 B2 2/2013 Cheng et al.  
2008/0001169 A1 1/2008 Lochtefeld  
2010/0078680 A1 4/2010 Cheng et al.

N. D. Nguyena et al, Selective epitaxial growth of III-V semiconductor heterostructures on Si substrates for logic applications, ECS Transactions, 33 (6) 933-939 (2010), pp. 933-939.

G. Wang et al, Growth of high quality InP layers in Si trench on miscut Si (001) substrates, Journal of Crystal Growth 315 (2011), pp. 32-36.

M. Cantoroa et al, Heteroepitaxy of III-V Compound Semiconductors on Silicon for Logic Applications: Selective Area Epitaxy in Shallow Trench Isolation Structures vs. Direct Epitaxy mediated by Strain Relaxed Buffers, pp. 1-7.

G. Wang et al, Selective area growth of high quality InP on Si .., 001 . . . substrates, Applied Physics Letters 97, 121913 (2010), pp. 1-3.

\* cited by examiner

FIG. 1

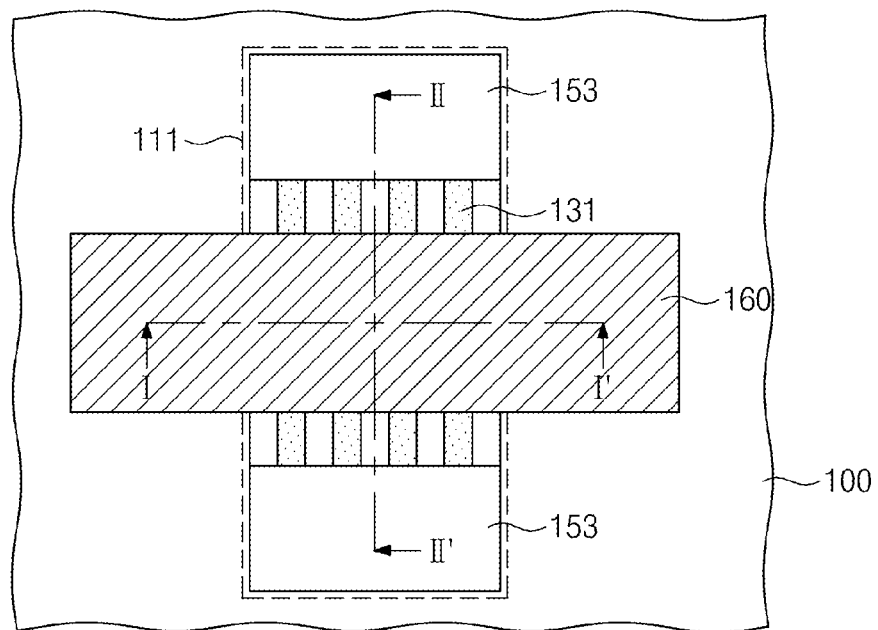


FIG. 2A

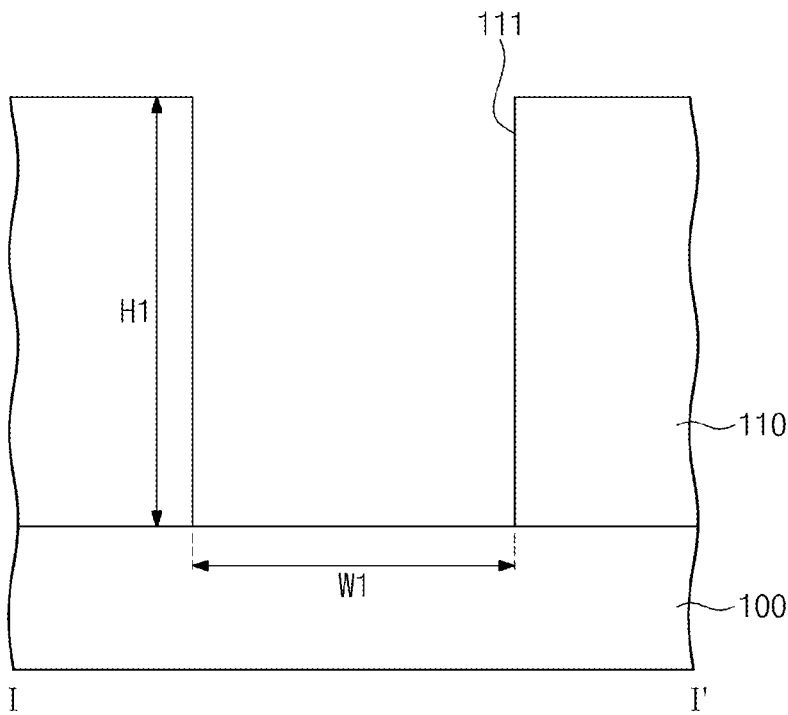


FIG. 2B

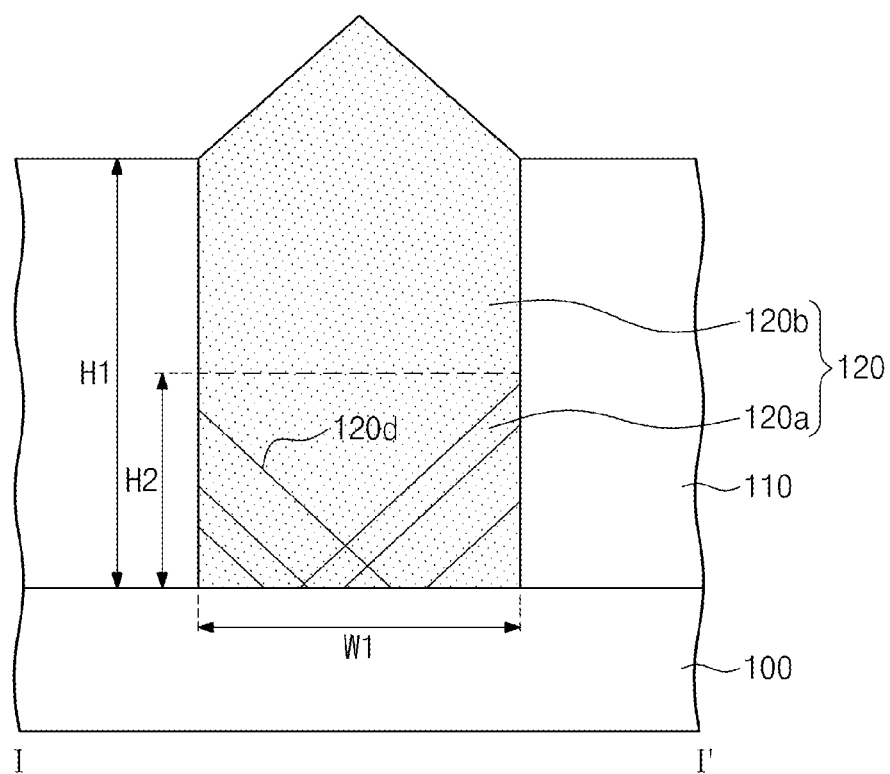


FIG. 2C

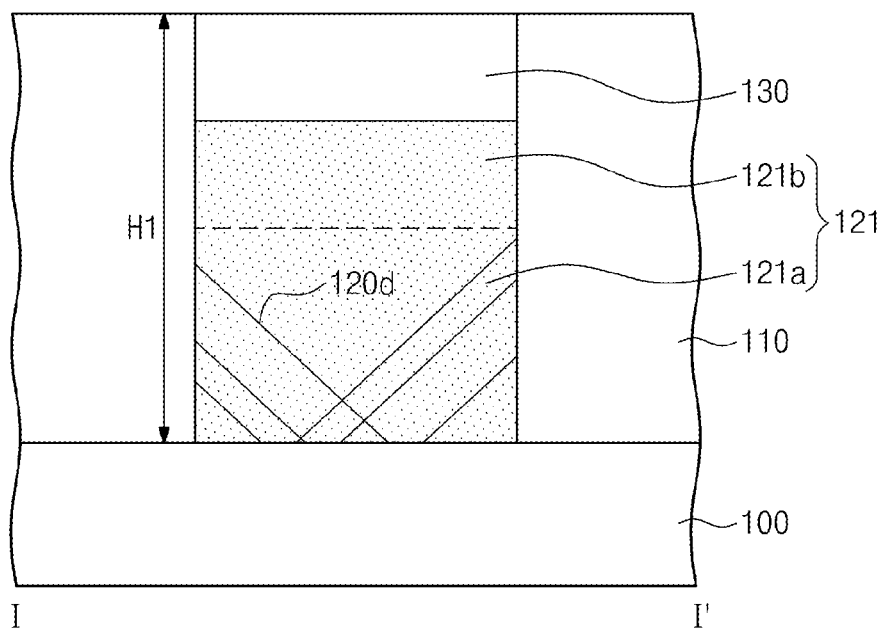


FIG. 2D

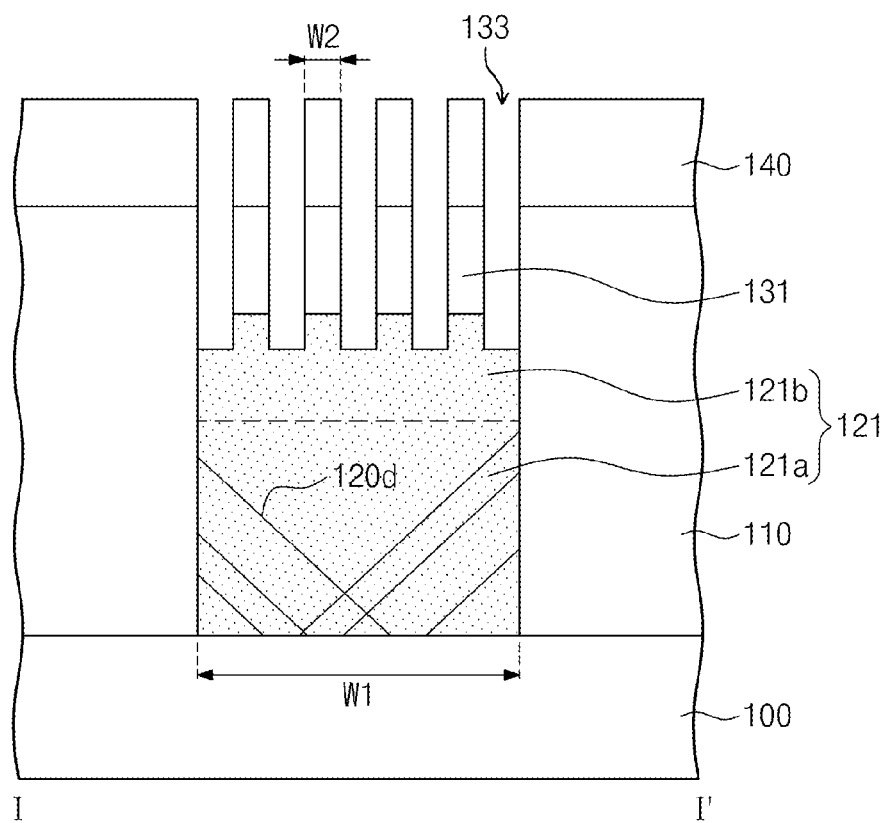


FIG. 2E

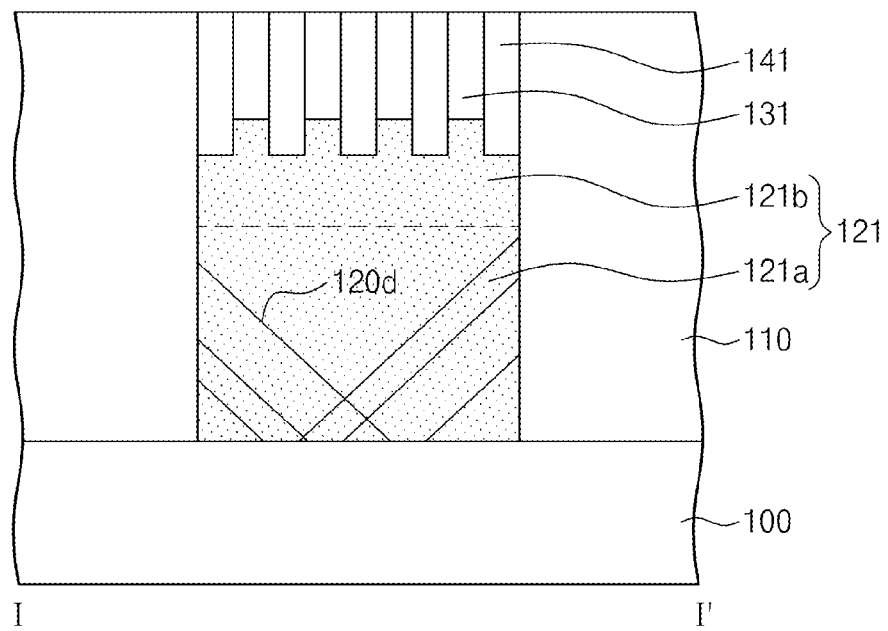




FIG. 2F

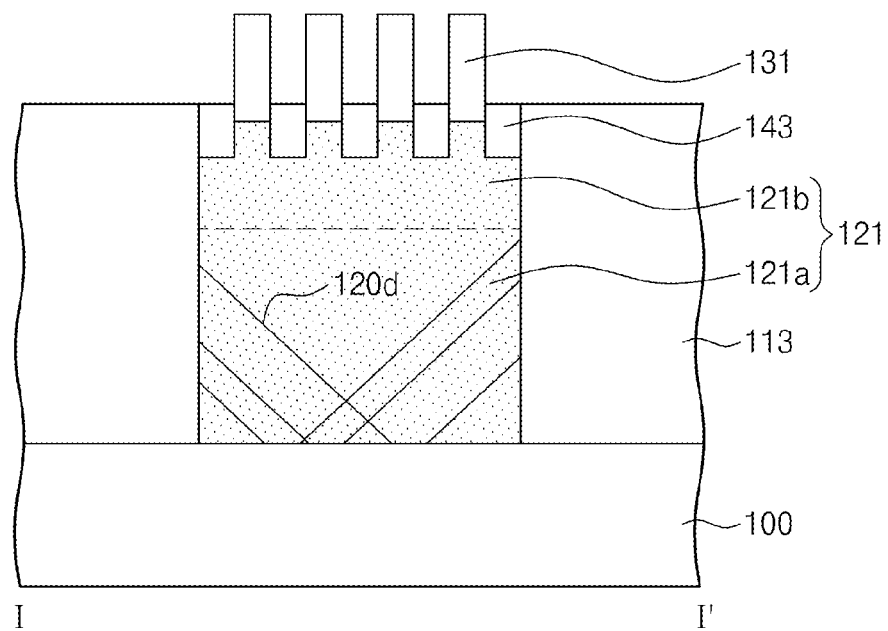


FIG. 2G

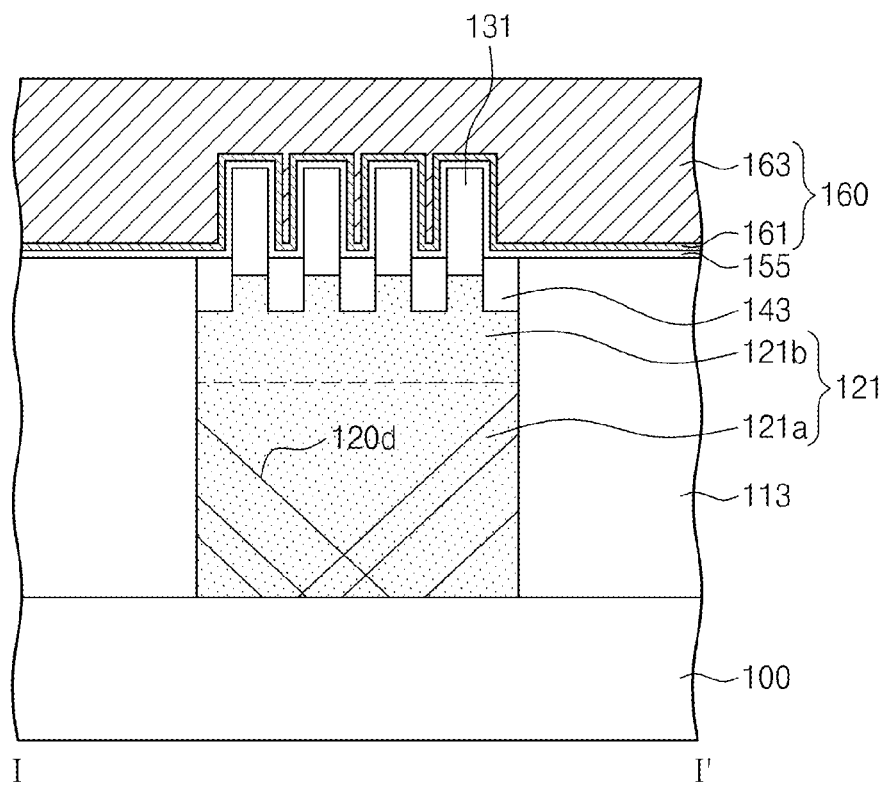


FIG. 3

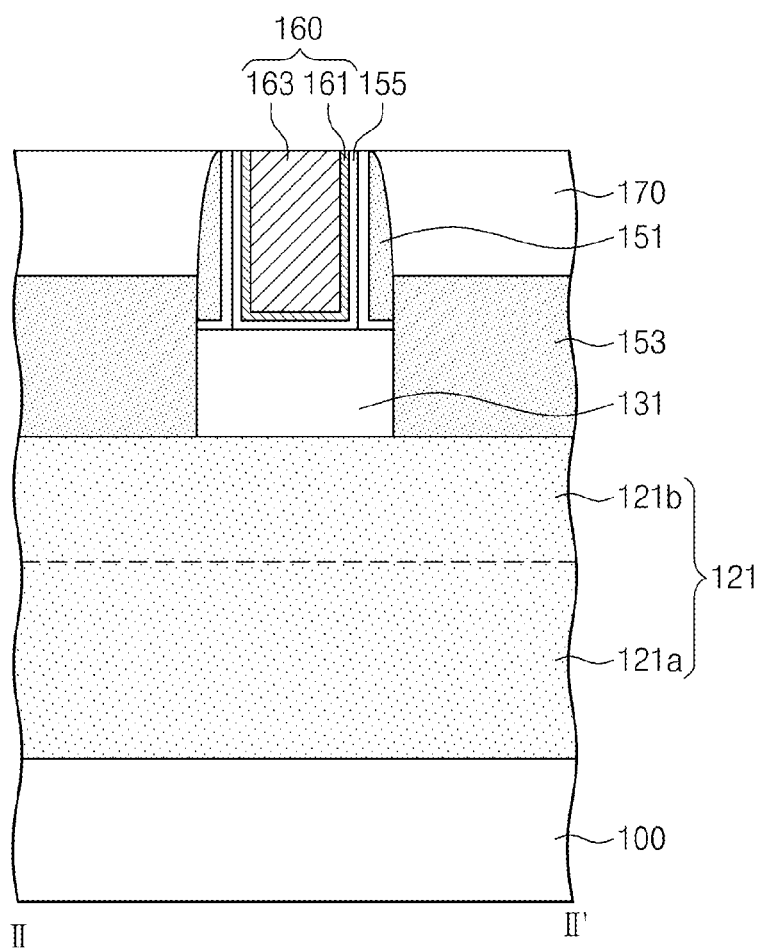


FIG. 4

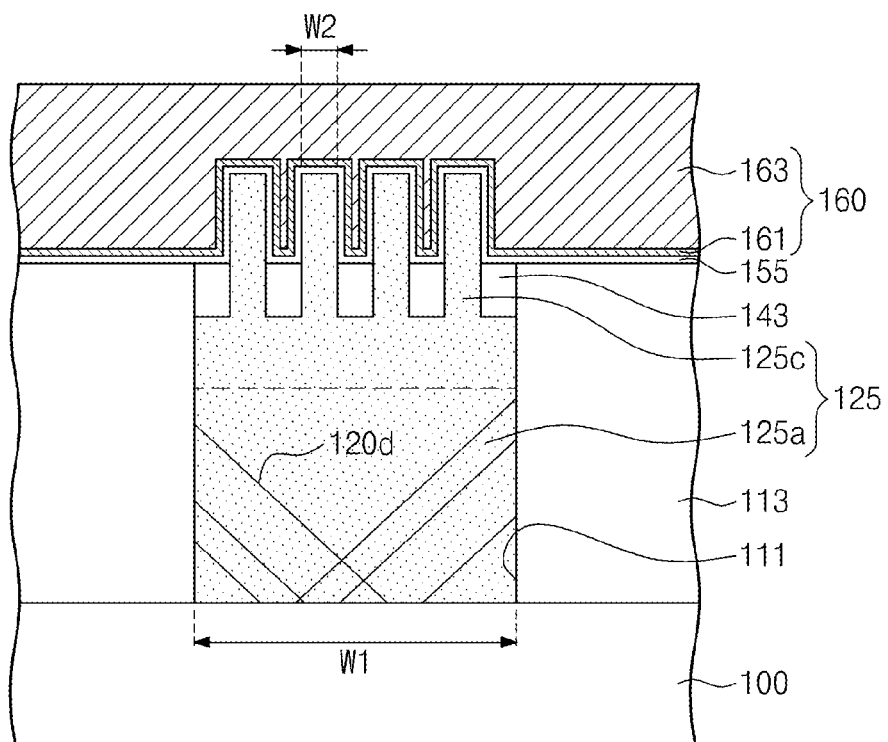


FIG. 5

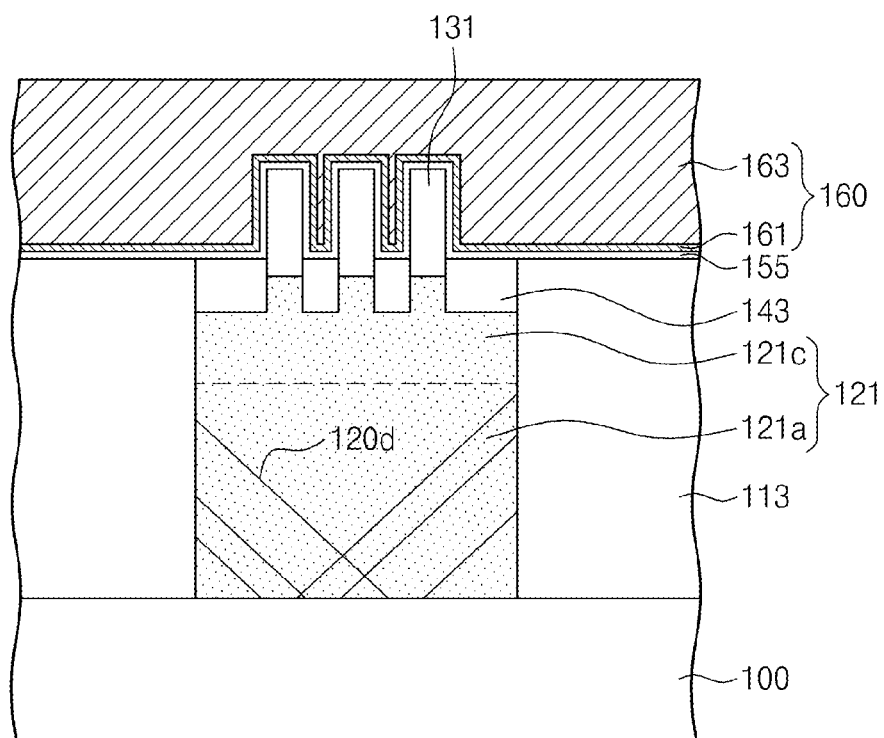


FIG. 6

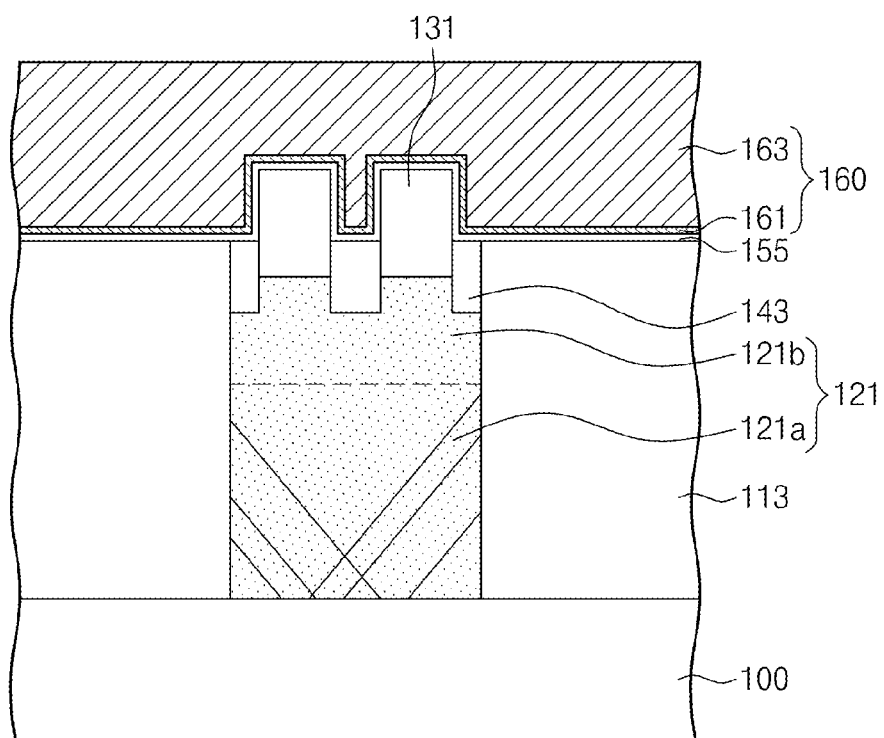


FIG. 7

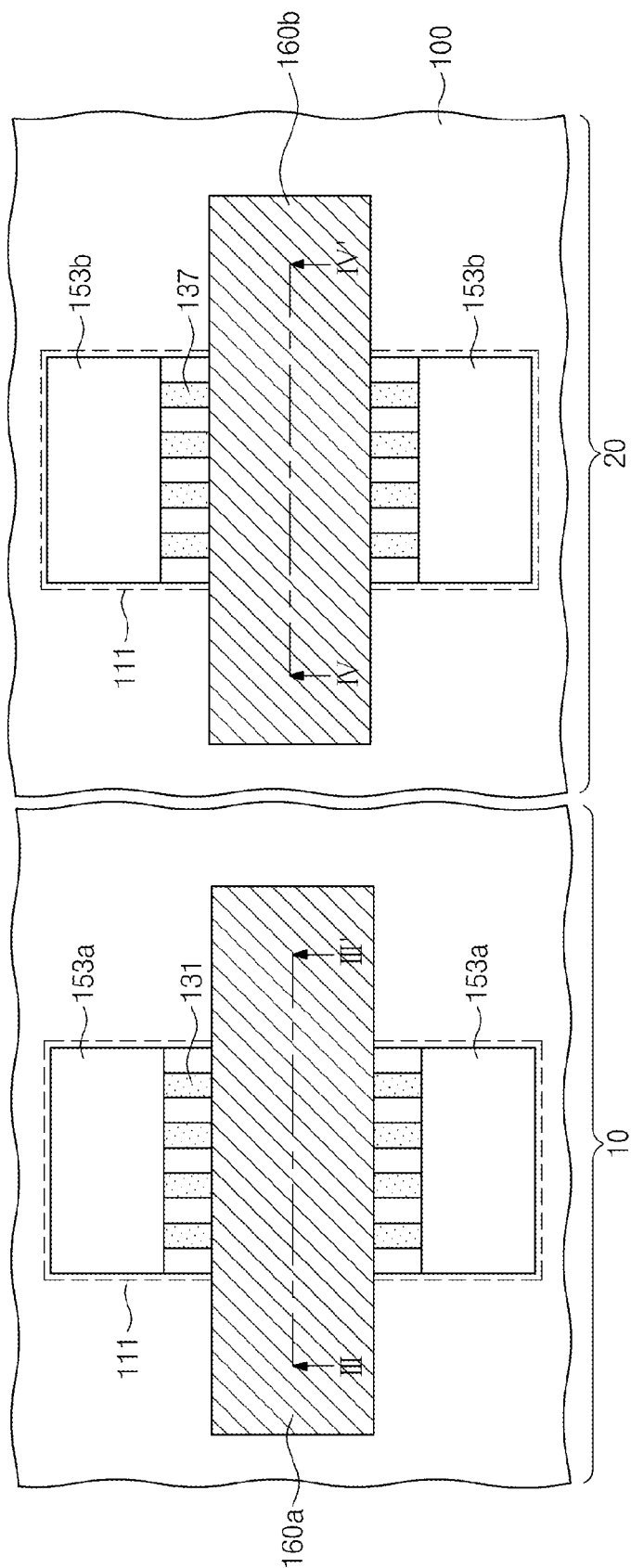


FIG. 8A

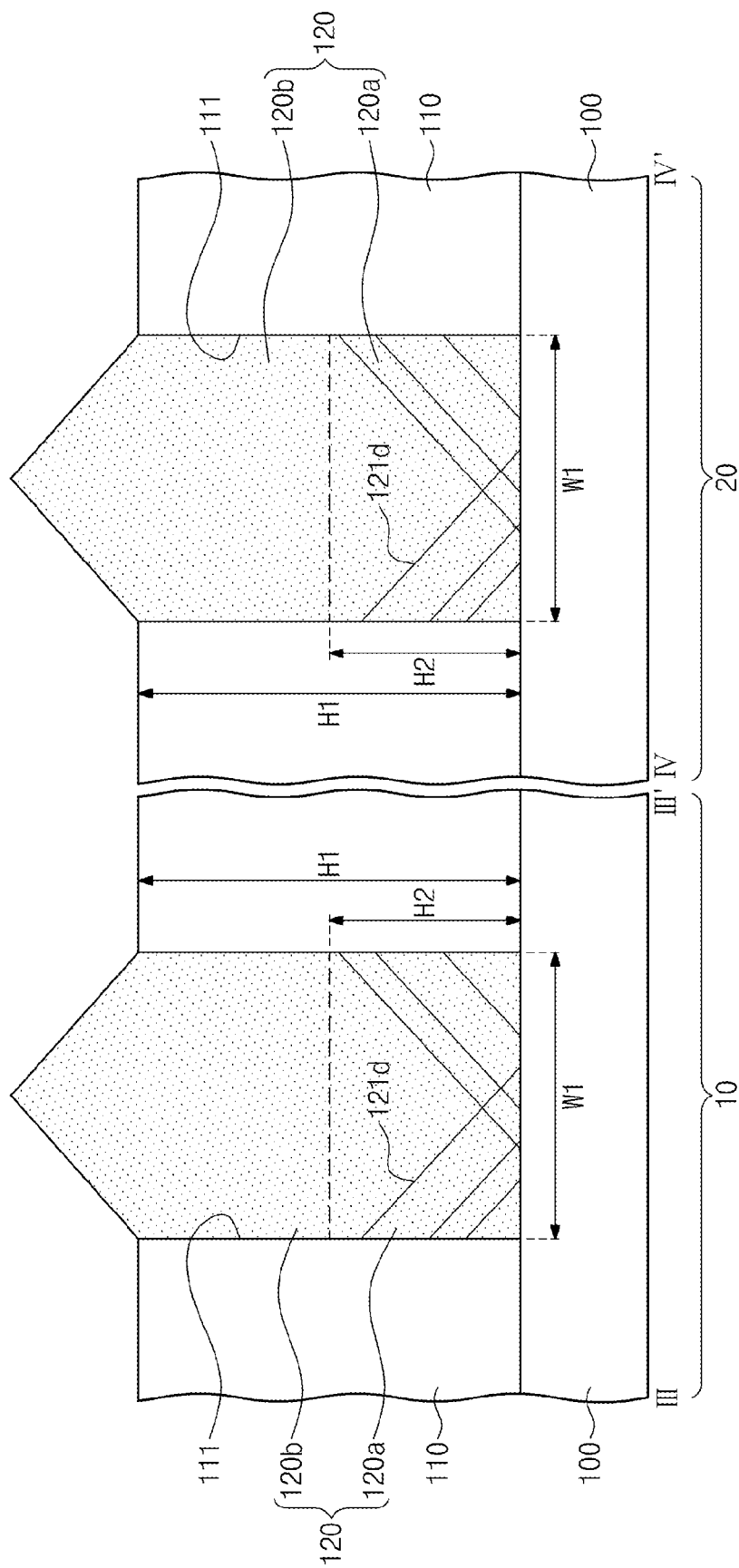




FIG. 8B

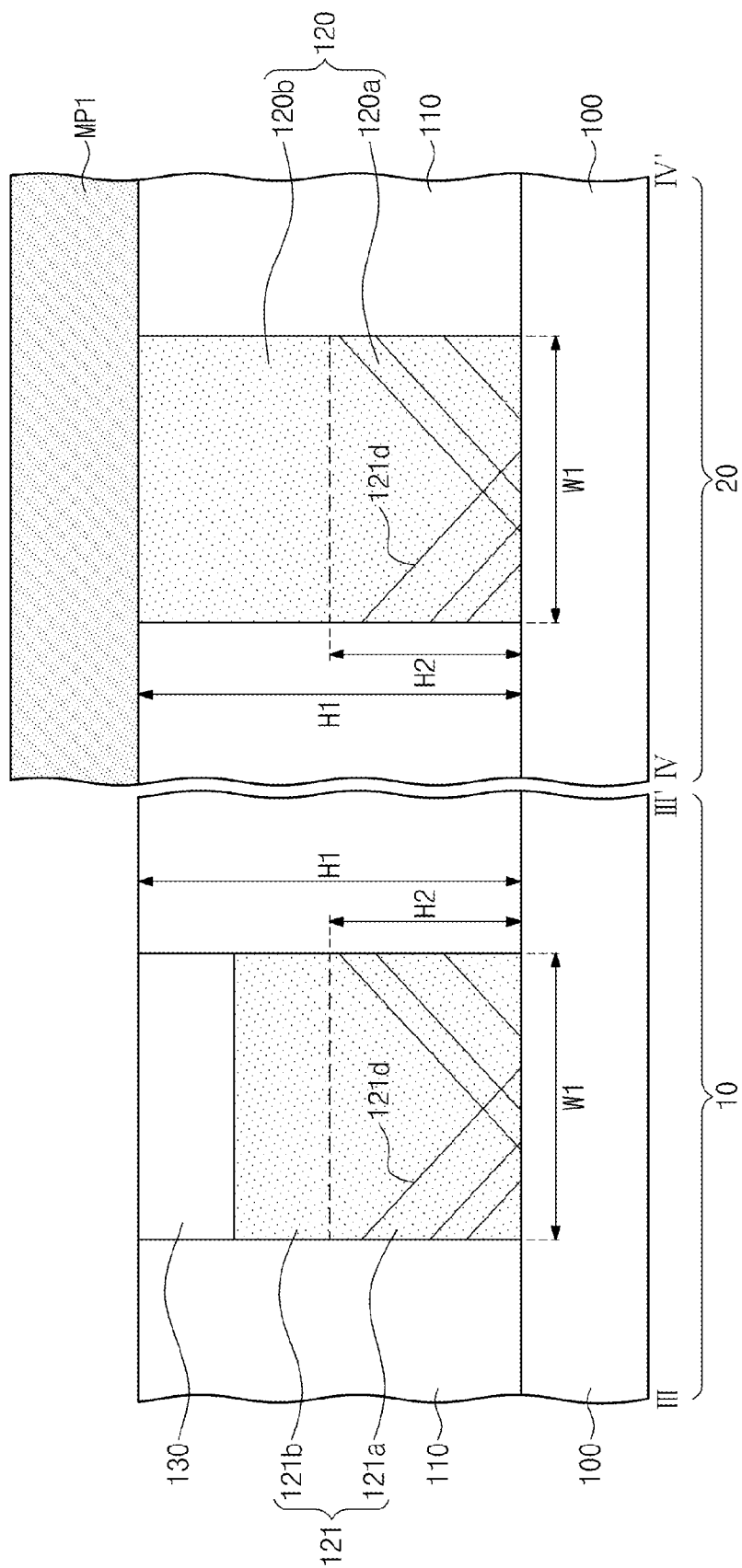


FIG. 8C

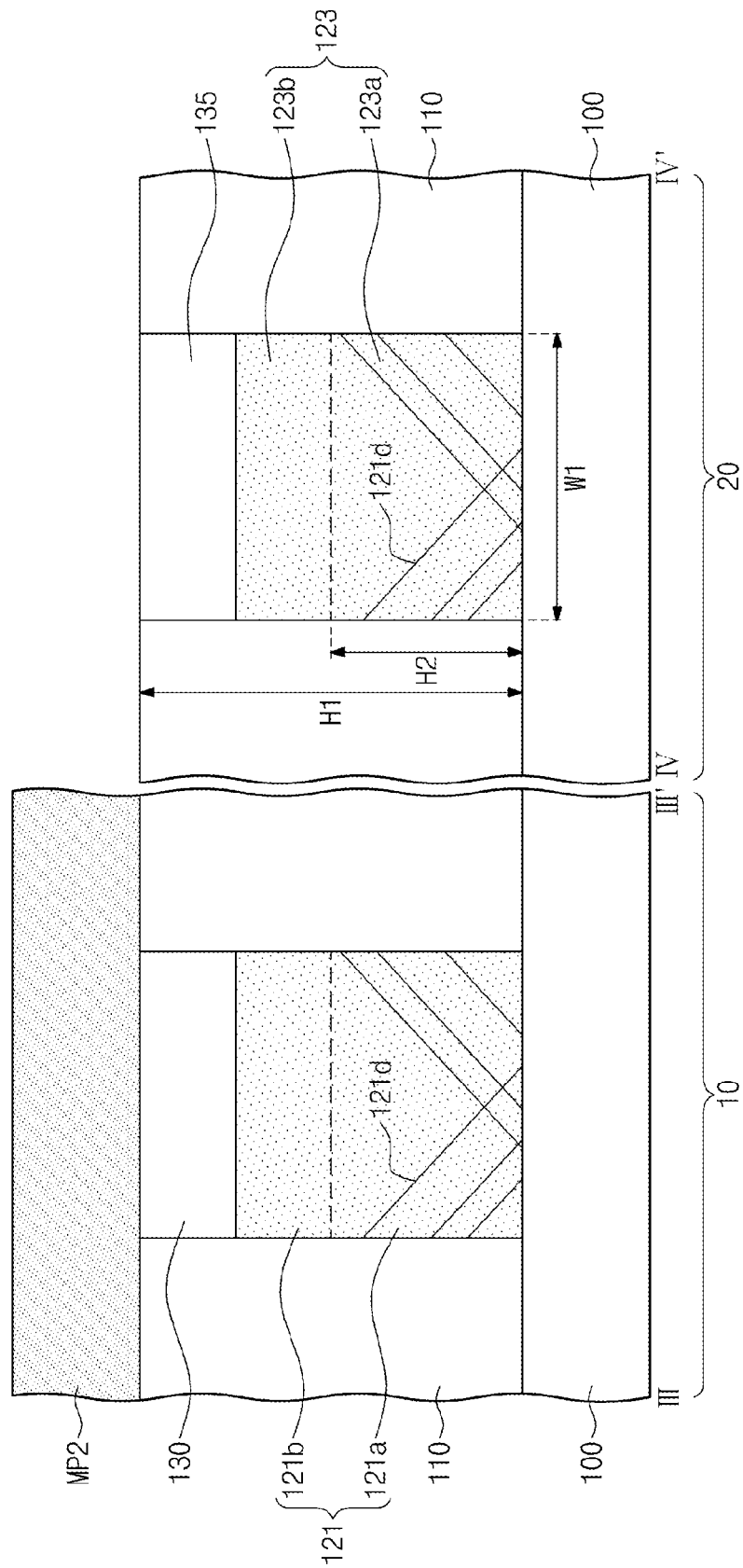


FIG. 8D

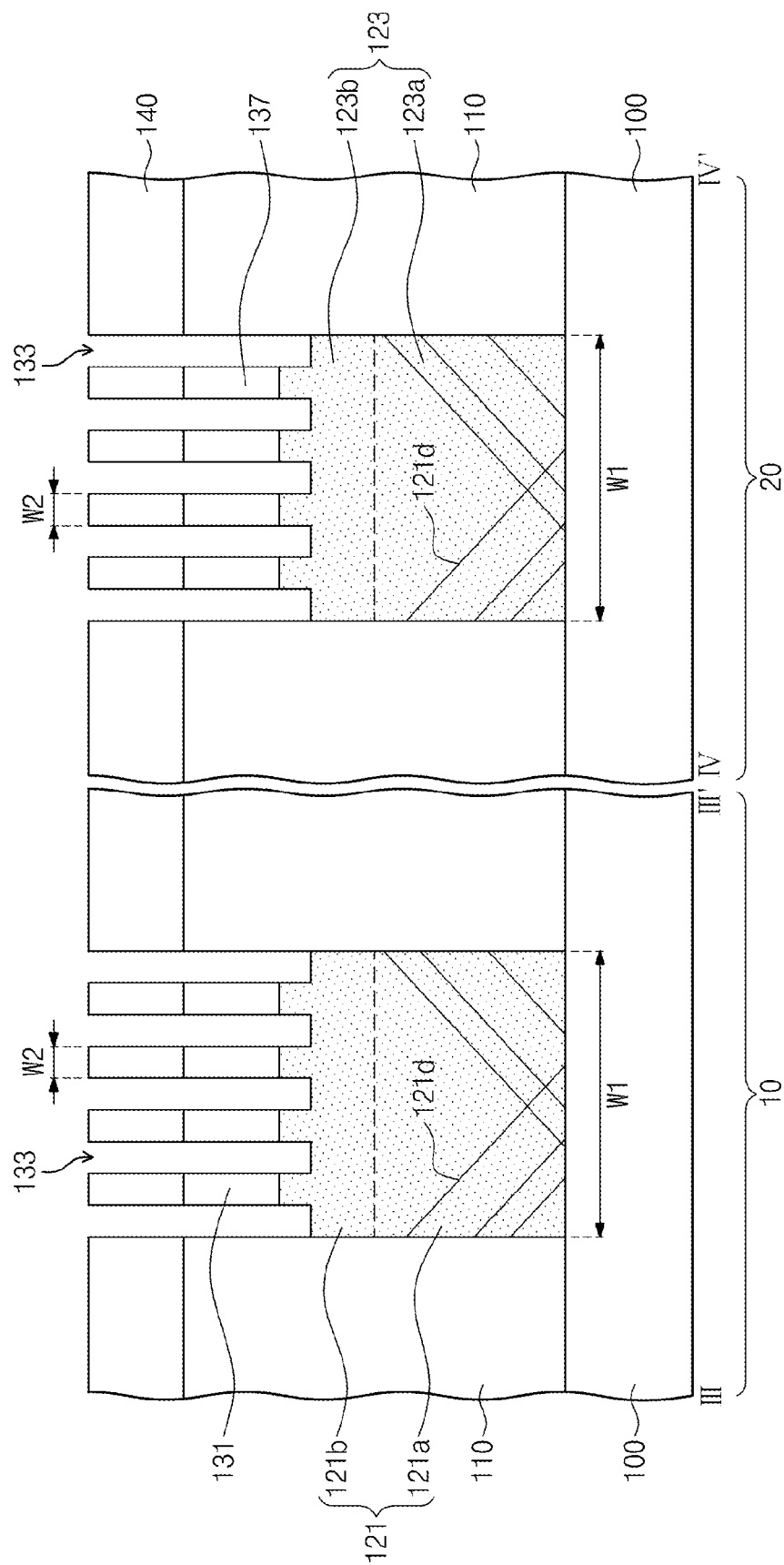


FIG. 8E

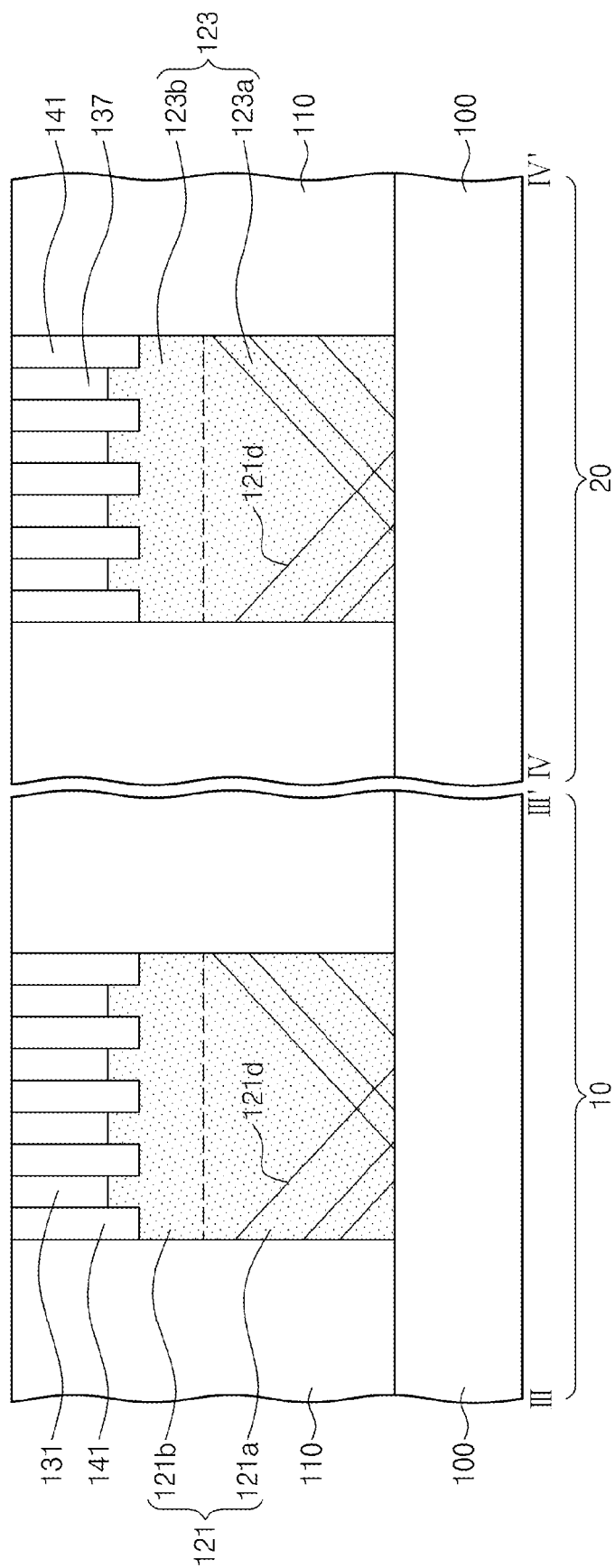


FIG. 8F

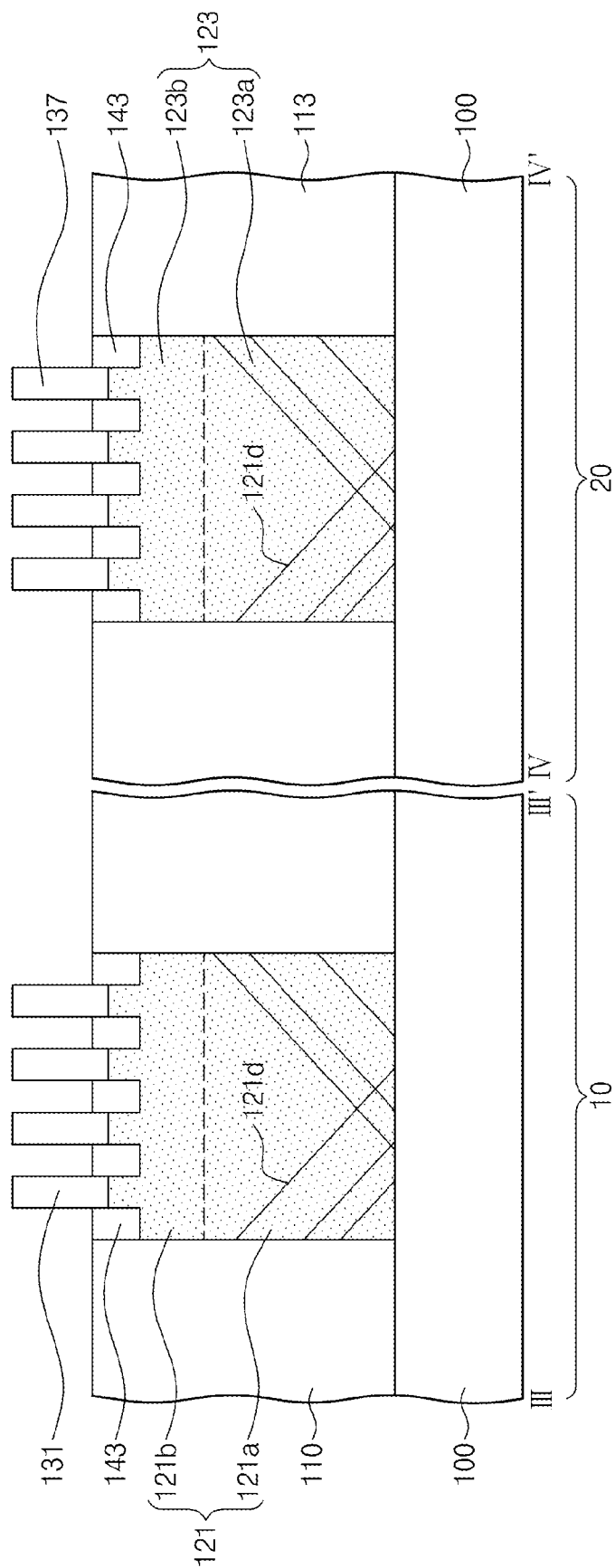


FIG. 8G

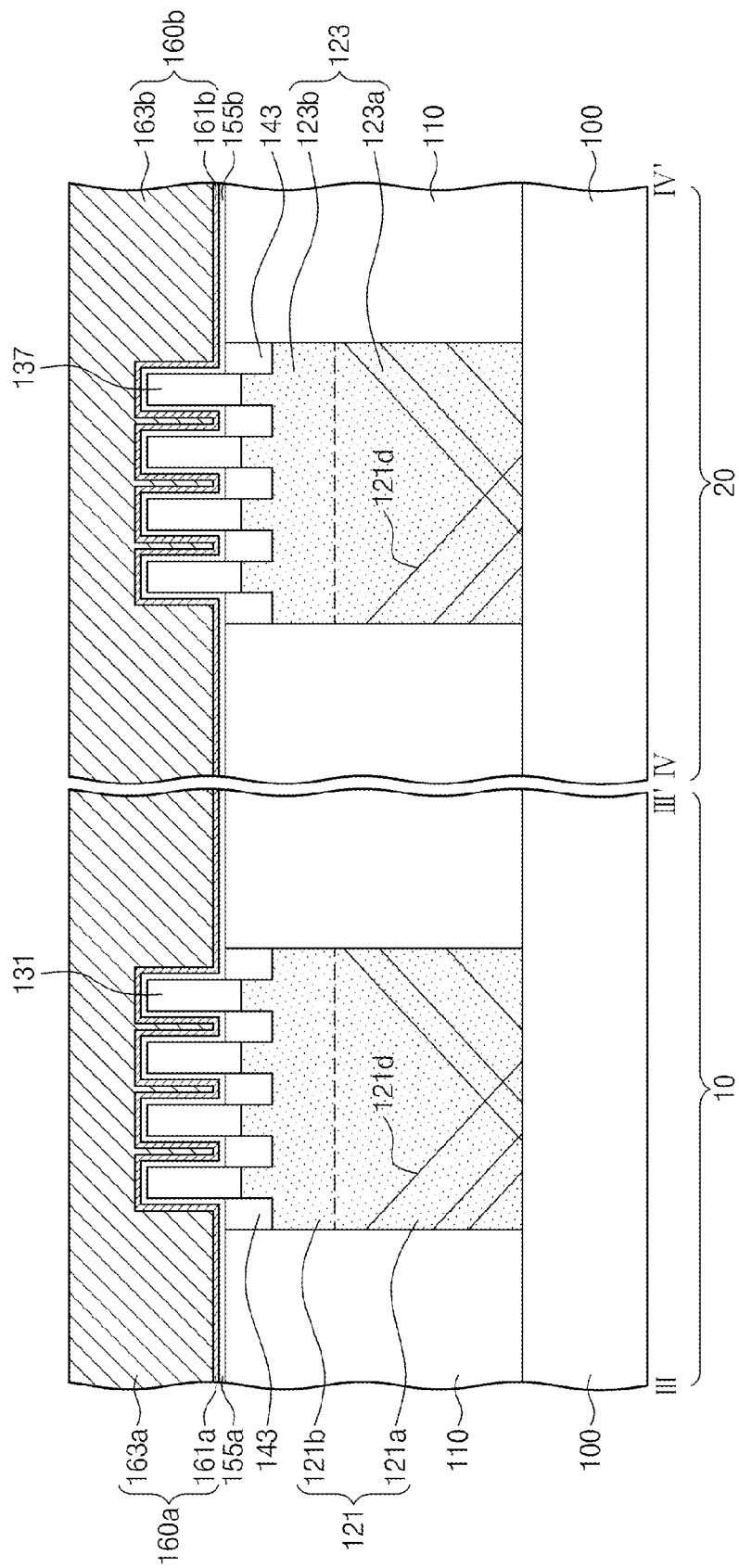


FIG. 9

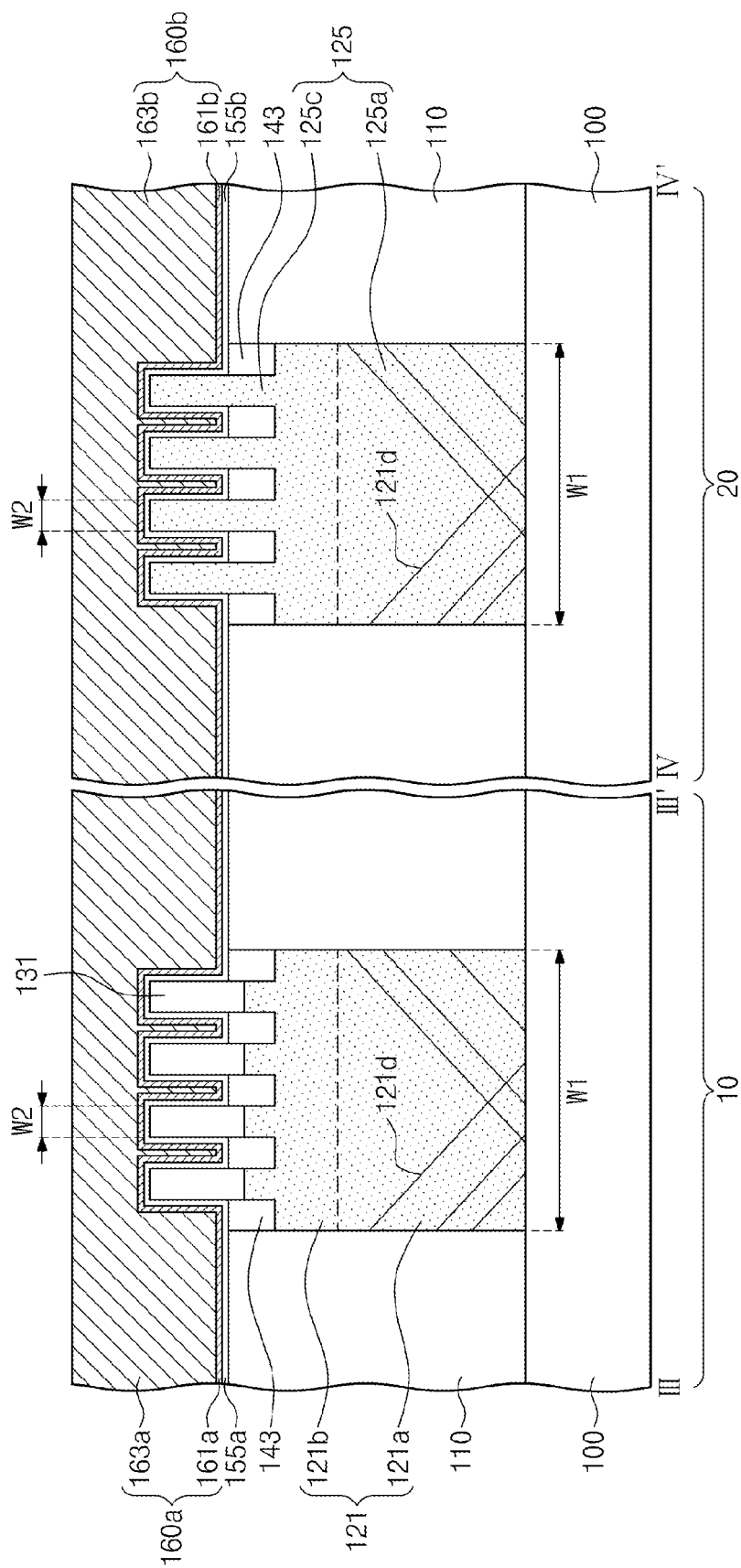


FIG. 10

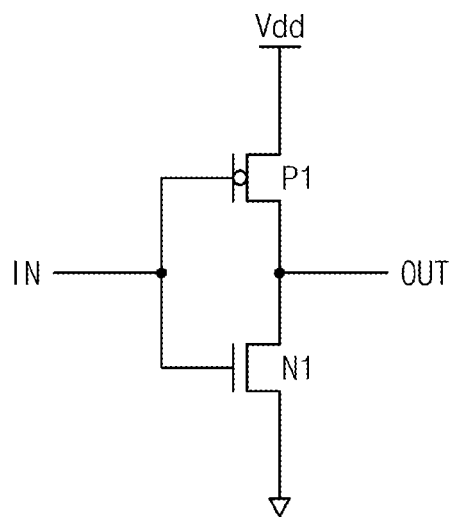


FIG. 11

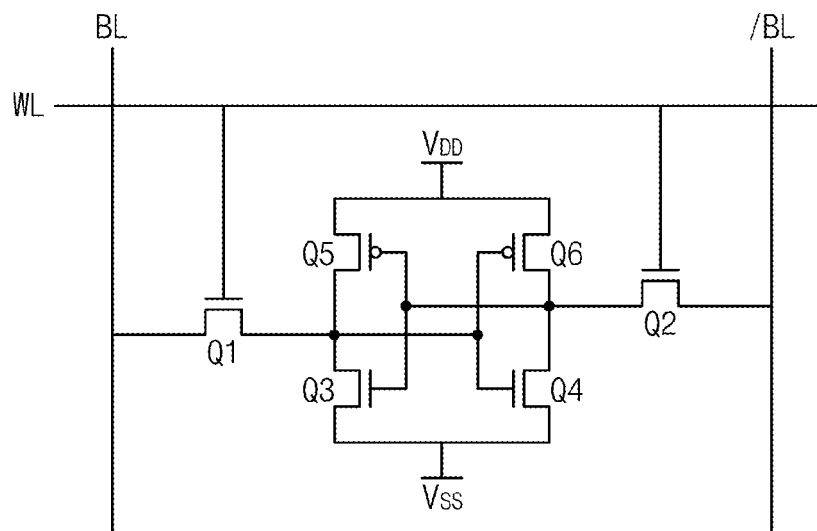
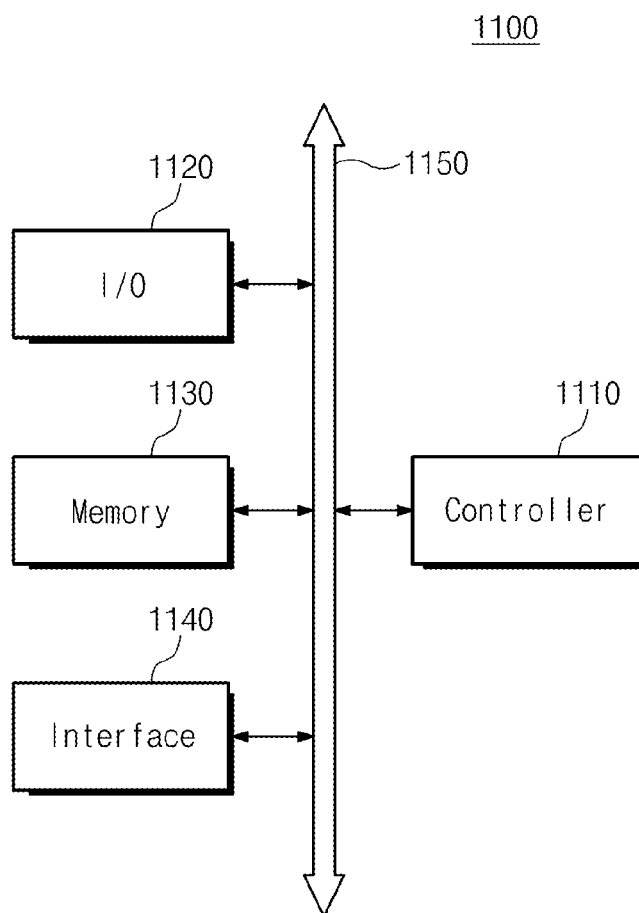




FIG. 12



# SEMICONDUCTOR FIN DEVICES AND METHOD OF FABRICATING THE SEMICONDUCTOR FIN DEVICES

## CROSS-REFERENCE TO RELATED APPLICATION

A claim of priority under 35 U.S.C. §119 is made to Korean Patent Application No. 10-2014-0024075, filed on Feb. 28, 2014, in the Korean Intellectual Property Office, the entire disclosure of which is hereby incorporated by reference.

## BACKGROUND

The inventive concepts generally relate to semiconductor devices and to methods of fabricating the semiconductor devices. More particularly, the inventive concepts relate to fin field effect transistors and to methods of fabricating fin field effect transistors.

A semiconductor device may include an integrated circuit (IC) made up of a plurality of Metal Oxide Semiconductor Field Effect Transistors (MOSFETs or MOS transistors for short). Reducing the size and design rule of such a semiconductor device, i.e., increasing the degree of integration of the device, may thus require a scaling-down of MOS transistors. However, such scaling-down of MOS transistors may compromise certain operational characteristics of the semiconductor device. Accordingly, research is being conducted on various techniques aimed at fabricating highly integrated semiconductor devices that offer high performance. In particular, research is being conducted on ways to increase the mobility of charge carriers (electrons or holes) in MOS transistors with the aim of developing high-performance semiconductor devices.

## SUMMARY

According to example embodiments of the inventive concepts, a semiconductor device is provided which includes a substrate, an insulating layer disposed on the substrate and having a trench exposing a surface portion of the substrate, and a channel-forming structure comprising crystalline semiconductor material. The channel-forming structure has a lower portion located in the trench and fins extending upright on the lower portion, where the fins are spaced from each other and are each narrower than an opening of the trench, and the lower portion of the channel forming structure has a higher crystal defect density than the fins of the channel forming structure.

The fins may be devoid of crystal defects.

The fins may extend along a length of the trench, may be spaced from each other in a widthwise direction of the trench, and may each be narrower than the trench in the widthwise direction.

The fins may extend upward beyond the opening of the trench.

The crystal defect density in the lower portion of the channel forming structure may increase in a depth direction of the trench.

The fins may include respective buffer patterns which are a unitary part of the lower portion of the channel-forming structure, and fin-shaped channel patterns on the respective buffer patterns, and the buffer patterns and the fin-shaped channel patterns may have different energy band gaps.

The fin-shaped channel patterns may comprise a material selected from the group consisting of Ge, SiGe, and a Group III-V semiconductor compound.

The buffer patterns and the fin-shaped channel patterns may be formed of Group III-V semiconductor compounds having respectively different energy band gaps.

The channel-forming structure may be a unitary body of semiconductor material, and the semiconductor material may be selected from the group consisting of Ge, SiGe, and a Group III-V semiconductor compound.

A depth-to-width aspect ratio of the trench may be between 1:1 and 3:1 both inclusive, and the width of the trench may be at least 50 nm.

The semiconductor device may further include a gate electrode extending longitudinally across the fins in the widthwise direction of the trench, a gate insulating layer interposed between the gate electrode and the fins, and source/drain regions in the trench at opposite ends of the fins.

According to other example embodiments of the inventive concepts, a semiconductor device is provided which includes a semiconductor substrate, an insulating layer disposed on the substrate and having a trench exposing a surface portion of the substrate, wherein a depth-to-width aspect ratio of the trench is between 1:1 and 3:1 both inclusive, and a crystalline channel-forming structure disposed in the trench. The crystalline channel-forming structure has an epitaxial lower portion disposed on the surface portion of the semiconductor substrate and occupying a bottom portion of the trench, and epitaxial fins extending upright on the lower portion, and the fins are spaced from each other in a widthwise direction of the trench and are each narrower than the trench in the widthwise direction.

The width of the trench may be at least 50 nm.

The epitaxial fins may include respective buffer patterns which are a unitary part of the epitaxial lower portion of the crystalline channel-forming structure, and fin-shaped epitaxial channel patterns on the respective buffer patterns, and the buffer patterns and the fin-shaped channel patterns may have different energy band gaps.

The buffer pattern and the fin-shaped channel patterns may be formed of Group III-V semiconductor compounds having respectively different energy band gaps.

The semiconductor device may further include a gate electrode extending longitudinally across the epitaxial fins in the widthwise direction of the trench, a gate insulating layer interposed between the gate electrode and the epitaxial fins, and source/drain regions in the trench at opposite ends of the epitaxial fins.

According to still other example embodiments of the inventive concepts, a semiconductor device is provided which includes a substrate, an insulating layer disposed on the substrate and having a first trench exposing a first surface portion of the substrate and a second trench exposing a second surface portion of the substrate, and first and second channel-forming structure comprising crystalline semiconductor material. The first channel-forming structure has a first lower portion located in the first trench and first fins extending upright on the first lower portion, where the first fins are of a first conductivity type, are spaced from each other and are each narrower than an opening of the first trench, and where the first lower portion of the first channel forming structure has a higher crystal defect density than the first fins of the first channel forming structure. The second channel-forming structure has a second lower portion located in the second trench and second fins extending upright on the second lower portion, where the second fins are of a second conductivity type, are spaced from each other and are each narrower than an opening of the second trench, and where the second lower

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portion of the second channel forming structure has a higher crystal defect density than the second fins of the second channel forming structure.

The semiconductor device may further include a first gate electrode extending longitudinally across the first fins in a widthwise direction of the first trench, a first gate insulating layer interposed between the first gate electrode and the first fins, and first source/drain regions in the first trench at opposite ends of the first fins, wherein the first fins, the first gate electrode, the first gate insulating layer, and the first source/drain regions constitute a PMOS transistor. The semiconductor device may still further include a second gate electrode extending longitudinally across the second fins in a widthwise direction of the second trench, a second gate insulating layer interposed between the second gate electrode and the second fins, and second source/drain regions in the second trench at opposite ends of the second fins, wherein the second fins, the second gate electrode, the second gate insulating layer, and the second source/drain regions constitute a NMOS transistor. The PMOS transistor and the NMOS transistor may be connected in a CMOS configuration.

According to yet other example embodiments of the inventive concept, a method of fabricating a semiconductor device is provided which includes providing an insulating layer on a semiconductor substrate and forming a trench in the insulating layer that exposes a surface portion of the substrate, forming an epitaxial buffer layer in the trench using the surface portion of the substrate as a seed, and forming epitaxial fins of semiconductor material at an upper surface of the epitaxial buffer layer, the epitaxial fins being spaced from each other and each being narrower than an opening of the trench.

The epitaxial fins may be formed by patterning an upper surface of the epitaxial buffer layer.

The method may further include, before forming the epitaxial fins, patterning the epitaxial buffer layer to form plural epitaxial buffer patterns at the upper surface of the epitaxial buffer layer, where the epitaxial fins are grown at the respective upper surfaces of the epitaxial buffer patterns using the epitaxial buffer patterns as a seed.

An energy band gap of the epitaxial fins may differ from an energy band gap of the epitaxial buffer patterns.

The epitaxial buffer patterns and the epitaxial fins may be each formed of one of Ge, SiGe and Group III-V semiconductor compounds having respectively different energy band gaps.

Bottoms of the epitaxial fins may be situated in the trench, and tops of the epitaxial fins may extend above the trench.

Selective epitaxial growth (SEG) processes may be utilized to form the epitaxial buffer layer and the epitaxial fins. The SEG processes may each be selected from the group consisting of solid phase epitaxy (SPE), vapor phase epitaxy (VPE), liquid phase epitaxy (LPE), molecular beam epitaxy (MBE), chemical vapor deposition (CVD), reduced pressure CVD (RPCVD) and ultra high vacuum CVD (UHCVD).

A depth-to-width aspect ratio of the trench may be between 1:1 and 3:1 both inclusive, and a width of the trench may be at least 50 nm.

The method may further include forming a gate insulating layer and a gate electrode conformally over the epitaxial fins across a width of the trench, and source/drain regions in the trench at opposite ends of the epitaxial fins.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The inventive concepts will become readily understood from the detailed description that follows, with reference to the accompanying drawings.

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FIG. 1 is a plan view of an embodiment of a semiconductor device according to the inventive concept.

FIGS. 2A, 2B, 2C, 2D, 2E, 2F and 2G are sectional views taken in the direction of line I-I' of FIG. 1 and collectively illustrate a method of fabricating a semiconductor device according to the inventive concept.

FIG. 3 is a sectional view taken in the direction of line II-IP of FIG. 1.

FIGS. 4, 5 and 6 are sectional views of other examples of a semiconductor device according to the inventive concept, respectively.

FIG. 7 is a plan view of another embodiment of a semiconductor device according to the inventive concept.

FIGS. 8A, 8B, 8C, 8D, 8E, 8F and 8G are sectional views taken in the direction of lines III-III' and IV-IV' of FIG. 7, and collectively illustrate another embodiment of a method of fabricating a semiconductor device according to the inventive concept.

FIG. 9 is a sectional view of another example of a semiconductor device according to the inventive concept.

FIG. 10 is a circuit diagram of a CMOS inverter including a CMOS transistor according to the inventive concept.

FIG. 11 is a circuit diagram of an SRAM device including a CMOS transistor according to the inventive concept.

FIG. 12 is a schematic block diagram of an example of an electronic system including a semiconductor device according to the inventive concept.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Various embodiments and examples of embodiments of the inventive concept will be described more fully hereinafter with reference to the accompanying drawings. In the drawings, the sizes and relative sizes and shapes of elements, layers and regions shown in section may be exaggerated for clarity. In particular, the cross-sectional illustrations of the semiconductor devices and intermediate structures fabricated during the course of their manufacture are generally schematic. Also, like numerals are used to designate like elements throughout the drawings.

It will also be understood that when an element or layer is referred to as being "on" or "connected to" another element or layer, it can be directly on or directly connected to the other element or layer or intervening elements or layers may be present. In contrast, when an element or layer is referred to as being "directly on" or "directly connected to" another element or layer, there are no intervening elements or layers present.

It will be understood that although the terms first, second, third etc. are used herein to describe various elements, regions, layers, etc., these elements, regions, and/or layers are not limited by these terms. These terms are only used to distinguish one element, layer or region from another.

Furthermore, spatially relative terms, such as "upper" and "lower" are used to describe an element's and/or feature's relationship to another element(s) and/or feature(s) as illustrated in the figures. Thus, the spatially relative terms may apply to orientations in use which differ from the orientation depicted in the figures. Obviously, though, all such spatially relative terms refer to the orientation shown in the drawings for ease of description and are not necessarily limiting as embodiments according to the inventive concept can assume orientations different than those illustrated in the drawings when in use. In addition, the terms "upper" or "top" and "lower" or "bottom" as used to describe a surface generally refer not only to the orientation depicted in the drawings but

to the fact that the surface is the uppermost or bottommost surface in the orientation depicted, as would be clear from the drawings and context of the written description.

Other terminology used herein for the purpose of describing particular examples or embodiments of the inventive concept is to be taken in context. For example, the terms “comprises” or “comprising” when used in this disclosure specifies the presence of stated features or processes but does not preclude the presence or additional features or processes. Furthermore, the term “width” will refer to the shorter dimension of a feature such as a trench elongated in a horizontal X-Y plane, i.e., the term “width” will refer to the dimension in the X-Y plane perpendicular to the direction in which the trench extends longitudinally in the X-Y plane. Also, the terms “height” and “thickness” will be generally understood as referring to the vertical dimension of a layer or feature, i.e., a dimension along a Z-axis perpendicular to the X-Y plane. Finally, the terms “substantially free of crystal defects” and “devoid of crystal defects” as used to describe a particular material/region will be understood to mean completely free of crystal defects or such a low density of crystal defects that no effect of any crystal defects on the function that material/region is observed.

An embodiment of a semiconductor device according to the inventive concept, and a method of fabricating the semiconductor device, will now be described in detail with reference to FIG. 1, FIGS. 2A through 2G, and FIG. 3.

Referring first to FIGS. 1 and 2A, an insulating layer **110** is formed on a semiconductor substrate **100**, and a first trench **111** is formed in the insulating layer **110** to expose a portion of the semiconductor substrate **100**.

The semiconductor substrate **100** may be a single crystalline silicon wafer. Alternatively, the semiconductor substrate **100** may be a silicon-on-insulator (SOI) wafer, a germanium wafer, a germanium-on-insulator (GOI) wafer, a silicon-germanium wafer, or a substrate including an epitaxial layer. Still further, the semiconductor substrate **100** may instead be of at least one Group III-V semiconductor compound.

The insulating layer **110** may be formed of at least one material selected from the group consisting of O<sub>3</sub>-Tetra Ethyl Ortho Silicate (O<sub>3</sub>-TEOS), Undoped Silicate Glass (USG), PhosphoSilicate Glass (PSG), Borosilicate Glass (BSG), BoroPhosphoSilicate Glass (BPSG), High Density Plasma (HDP) oxide, Undoped Silicate Glass (USG), Fluoride Silicate Glass (FSG), Spin On Glass (SOG) material, and Tonen SilaZene (TOSZ). Also, the insulating layer **110** may be formed using a Chemical Vapor Deposition (CVD) or spin coating process. The thickness to which the insulating layer **110** is formed will generally depend on the height to which a buffer layer **120** is to be formed in a subsequent process (FIG. 2B).

The first trench **111** can be formed by forming a mask (not shown) on the insulating layer **110** and anisotropically etching the insulating layer **110** using the mask (not shown) as an etch mask.

In the illustrated embodiment, the first trench **111** has a height (or depth) H1, which is substantially the same as the thickness of the insulating layer **110**, and a width W1, which may be about the same or less than the height H1. For example, the width W1 of the first trench **111** may range from about 50 nm to about 500 nm and the first trench **111** may have an aspect ratio (H1/W1) ranging from about 1 to about 3 both inclusive.

Referring to FIGS. 1 and 2B, a buffer layer **120** is formed to fill the first trench **111**.

The buffer layer **120** is formed of a semiconductor material, whose lattice constant is different from that of the semi-

conductor substrate **100**. For example, the buffer layer **120** may be of at least one material selected from the group consisting of Si, Ge, SiGe, and Group III-V semiconductor compounds. Examples of Group III-V semiconductor compounds include aluminum phosphide (AlP), gallium phosphide (GaP), indium phosphide (InP), aluminum arsenide (AlAs), gallium arsenide (GaAs), indium arsenide (InAs), aluminum antimonide (AlSb), gallium antimonide (GaSb), and indium antimonide (InSb).

In one example of this embodiment, the buffer layer **120** is formed by a selective epitaxial growth (SEG) process using the semiconductor substrate **100** as a seed layer. In this case, the selective epitaxial growth process may be solid phase epitaxy (SPE), vapor phase epitaxy (VPE), or liquid phase epitaxy (LPE). Other examples of processes for forming the buffer layer **120** include molecular beam epitaxy (MBE), chemical vapor deposition (CVD), reduced pressure CVD (RPCVD) and/or ultra high vacuum CVD (UHCVD).

In any case, a lower portion **120a** of the buffer layer **120** may have crystal defects whereas the upper portion **120b** is substantially free of crystal defects. Examples of the various crystal defects which may be produced in the lower portion **120a** of the buffer layer **120** include threading dislocations, stacking faults, twin boundaries, and anti-phase boundaries. Such crystal defects can be produced due to differences in the rates at which the crystals grow in different crystal planes under the selective epitaxial growth (SEG) process, for example.

An example will now be described in which threading dislocations **120d** are produced in the buffer layer **120** in the case in which the buffer layer **120** is formed using an SEG process. The threading dislocations **120d** tend to propagate or extend from the top surface of the semiconductor substrate toward a sidewall surface of the insulating layer **110** during the SEG process, but such propagation or extension of the threading dislocations **120d** can be blocked by the sidewall surface of the insulating layer **110**. Also, the threading dislocations **120d** may be formed at an angle of about 30-60 degrees relative to the top surface of the semiconductor substrate **100**. Accordingly, most of the threading dislocations **120d** formed during the SEG process may be trapped or localized in a region of the buffer layer **120**, i.e., in the aforementioned lower portion **120a**, confined below a specific height H2 from the top surface of the semiconductor substrate **100**. As a result, the density of the threading dislocations **120d** decreases in a vertical direction away from the semiconductor substrate **100**.

As mentioned above, the first trench **111** may be formed such that the height H1 thereof is one to three times the width W1 of the first trench **111**. This is to more effectively trap or localize the crystal defects in the lower portion **120a** of the first buffer layer **120**. In this case, the height H2 of the region (i.e., the lower portion **120a** of the buffer layer **120**), in which most of the crystal defects are trapped, is dictated by the angle at which the threading dislocations **120d** propagate or extend from the top surface of the semiconductor substrate **100** and the width W1 of the first trench **111**.

In the illustrated embodiment, the buffer layer **120** is formed to fill the first trench **111**. Furthermore, the buffer layer **120** may be formed by an SEG process in an over-growth manner such that the top surface of the buffer layer **120** extends higher than does that of the insulating layer **110**. Also, as is shown in FIG. 2B, the top surface of the buffer layer **120** may have facets, each of which is disposed at an acute angle relative to the top surface of the semiconductor

substrate **100**. The facets are naturally produced by the SEG process due to differences in the growth rates of crystals, in different crystal planes.

The buffer layer **120** may then be planarized to remove that portion of the buffer layer **120** protruding from the top surface of the insulating layer **110**. In this respect, the buffer layer **120** may be planarized using an etch-back process and/or a chemical mechanical polishing (CMP) process.

In any case, if the first trench **111** were too narrow and the buffer layer **120** were formed by an SEG process, the buffer layer **120** would have crystal defects throughout due to non-uniform growth of the crystals during the SEG process. In other words, as the semiconductor device is scaled-down, i.e., as the buffer layer **120** becomes more narrow, it becomes more and more difficult to provide the buffer layer **120** with a good crystalline property. On the other hand, as will be clear from the description that follows, according to the inventive concept, a plurality of fine patterns (e.g., fin-shaped channel patterns **131**) whose widths are smaller than the width **W1** of the first trench **111** are formed from crystalline semiconductor material that is substantially free of crystal defects.

Next, and referring to FIGS. 1 and 2C, in this embodiment, the buffer layer **120** is recessed to form a buffer pattern **121** exposing an upper portion of the sidewall surface of the first trench **111**. The recessing of the buffer layer **120** can be carried out by anisotropically etching the planarized buffer layer **120** using etchant having an etch selectivity with respect to the insulating layer **110**. As a result, the height (or thickness) of the buffer pattern **121** is smaller than the thickness **H1** of the insulating layer **110**.

Furthermore, the recessing of the buffer layer **120** is controlled such that the top surface of the buffer pattern **121** does not include any of the crystal defects that were present in the lower portion **120a** of the buffer layer. That is, the recessing of the buffer layer **120** is controlled such that a lower portion **121a** of the buffer pattern **121** has crystal defects whereas an upper portion **121b** of the buffer pattern **121** is substantially free of crystal defects.

Next, a channel layer **130** is formed on the buffer pattern **121** to fill the upper portion of the first trench **111**. The channel layer **130** has a band gap different from, e.g., smaller than, that of the buffer pattern **121**. In addition, the buffer pattern **121** may exert a compressive or tensile stress on the channel layer **130** so that the channel layer **130** is a strained channel layer.

To one or more of these ends, the channel layer **130** may be formed of at least one material selected from the group consisting of Si, Ge, SiGe, and Group III-V semiconductor compounds. Examples of Group III-V semiconductor compounds include aluminum phosphide (AlP), gallium phosphide (GaP), indium phosphide (InP), aluminum arsenide (AlAs), gallium arsenide (GaAs), indium arsenide (InAs), aluminum antimonide (AlSb), gallium antimonide (GaSb), and indium antimonide (InSb).

In one set of examples of this embodiment, the buffer pattern **121** is formed of SiGe, and the channel layer **130** is formed of Si or Ge.

In another example, the buffer pattern **121** and the channel layer **130** are each formed of SiGe, but the Ge concentration differs among the buffer pattern **121** and the channel layer **130**.

In other examples, the buffer pattern **121** and the channel layer **130** are formed of Group III-V semiconductor compounds whose energy band gaps are different from each other. In this case, the compounds may be the same. That is, the channel layer **130** may be formed of the same compound as the buffer pattern **121**, but the ratio of the elements constitut-

ing the compound of the channel layer **130** differ from the ratio of the elements constituting the compound of the buffer layer pattern **121**.

Furthermore, the channel layer **130** may include a quantum well layer and a capping layer. In this case, the quantum well layer may have an energy band gap that is smaller than that of the buffer layer **120**. For example, the quantum well layer may include Si, Ge, SiGe, or a Group III-V semiconductor compound, and the capping layer may include Si or SiGe.

In an example of the method of fabricating the semiconductor device according to the inventive concept, the channel layer **130** is formed by a SEG process using the semiconductor substrate **100** as a seed layer. In this case, the selective epitaxial growth process may include solid phase epitaxy (SPE), vapor phase epitaxy (VPE) and/or liquid phase epitaxy (LPE). Alternatively, the channel layer **130** may be formed using at least one of molecular beam epitaxy (MBE), chemical vapor deposition (CVD), reduced pressure CVD (RPCVD), and ultra high vacuum CVD (UHCVD).

If the SEG process is used and performed in an over growth manner, the channel layer **130** protrudes upward beyond the level of the top surface of the insulating layer **110**. In this case, a planarization process (for example, a CMP process) may be performed to remove the protruding portion of the channel layer **130**.

Referring to FIGS. 1 and 2D, the channel layer **130** is patterned to form a plurality of fin-shaped channel patterns **131** on the buffer pattern **121**.

The fin-shaped channel patterns **131** can be formed by forming a mask **140** on the insulating layer **110** to expose portions of the channel layer **130**, and then, anisotropically etching the channel layer **130** using the mask **140** as an etch mask to form second trenches **133** which delimit the fin-shaped channel patterns **131**. Each of the second trenches **133** may be formed to narrower than the first trench **111** (in the widthwise direction perpendicular to the longitudinal direction of the trenches). In the illustrated example, the second trenches **133** also expose part of the sidewall surface of the insulating layer **110**. In addition, the buffer pattern **121** may be partially etched, when the second trenches **133** are formed. Accordingly, the buffer pattern **121** may also include a plurality of fin-shaped portions, with the fin-shaped patterns **131** extending upright on the fin-shaped portions of the buffer pattern **121**, respectively.

In any case, the width **W2** of each of the fin-shaped channel patterns **131** is smaller than the width **W1** of the first trench **111** (and buffer pattern **121** at the bottom of the first trench **111**). For example, the width **W2** of each of the fin-shaped channel patterns **131** may be about  $\frac{1}{2}$  to  $\frac{1}{10}$  times the width **W1** of the first trench **121**. Thus, in an actual embodiment, the width **W2** of each of the fin-shaped channel patterns **131** may range from about 10 nm to about 50 nm. Also, the distance between adjacent ones of the fin-shaped channel patterns **131** may differ from the distance between the sidewall surface of the insulating layer **110** and the fin-shaped channel pattern **131** closest thereto.

Referring to FIGS. 1 and 2E, an insulating gap-filling layer **141** is formed to fill the second trenches **133**.

The insulating gap-filling layer **141** is preferably formed of an insulating material having a good gap-filling property. Furthermore, the insulating gap-filling layer **141** may be formed of the same insulating material as the insulating layer **110**. For example, the insulating gap-filling layer **141** may be formed of at least one material selected from the group consisting of O3-Tetra Ethyl Ortho Silicate (O3-TEOS), Undoped Silicate Glass (USG), PhosphoSilicate Glass (PSG), Borosilicate Glass (BSG), BoroPhosphoSilicate

Glass (BPSG), High Density Plasma (HDP) oxide, Undoped Silicate Glass (USG), Fluoride Silicate Glass (FSG), Spin On Glass (SOG) material, and Tonen SilaZene (TOSZ). Furthermore, the insulating gap-filling layer **141** may be formed using a deposition process having a good step coverage property. Next, the insulating gap-filling layer **141** may be planarized to expose top surfaces of the fin-shaped channel patterns **131**. The planarization of the gap-filling layer **141** may be effected by an etch-back process and/or a CMP process.

Referring to FIGS. **1** and **2F**, the insulating layer **110** and the insulating gap-filling layer **141** are etched to expose side-wall surfaces of the fin-shaped channel patterns **131**.

For example, the insulating layer **110** and the insulating gap-filling layer **141** may be selectively etched using etchant having an etch selectivity with respect to the fin-shaped channel patterns **131**. Accordingly, a recessed insulating layer **113** is produced around the buffer pattern **121**, and an insulating gap-filling pattern **143** is formed between the fin-shaped channel patterns **131**. In an example of this embodiment, top surfaces of the recessed insulating layer **113** and the insulating gap-filling pattern **143** are coplanar and located at a level between the respective levels of the tops and bottoms of the fin-shaped channel patterns **131**.

Referring to FIGS. **1**, **2G**, and **3**, a gate insulating layer **155** may be conformally formed over the surfaces of the fin-shaped channel patterns **131**, and a gate electrode **160** may be formed to cross the fin-shaped channel patterns **131**.

For example, a dummy gate pattern (not shown) is formed across the fin-shaped channel patterns **131**, insulating spacers **151** are formed on both sidewalls of the dummy gate pattern, the dummy gate pattern is removed to form a gate region exposing the fin-shaped channel patterns **131** between the insulating spacers **151**, and then, the gate insulating layer **155** and the gate electrode **160** are sequentially formed in the gate region. Furthermore, before the gate electrode **160** has been formed, source and drain electrodes **153** may be formed in portions of the fin-shaped channel patterns **131** located at both sides of the dummy gate pattern.

Alternatively, the gate insulating layer **155** and a gate conductive layer may be sequentially formed to cover the fin-shaped channel patterns **131**, and then, the gate insulating layer **155** and the gate conductive layer are patterned to form the gate electrode **160**. After the gate electrode **160** has been formed, the source and drain electrodes **153** are formed in portions of the fin-shaped channel patterns **131** located at both sides of the gate electrode **160**.

The gate insulating layer **155** may be formed of a high-k dielectric (e.g., hafnium oxide, hafnium silicate, zirconium oxide, or zirconium silicate). The gate insulating layer **155** may be formed using an atomic layer deposition process, and thus, the gate insulating layer **155** may conform to the topography of the side and top surfaces of the fin-shaped channel patterns **131**. Alternatively, the gate insulating layer **155** may be formed by thermally oxidizing the exposed surfaces of the fin-shaped channel patterns **131**.

The gate electrode **160** may be formed in such a way that the thickness of the portion thereof on the top surface of the insulating layer **110** is greater than the thickness of the portion thereof on the top surfaces of the fin-shaped channel patterns **131**. Furthermore, the gate electrode **160** may be formed to fill what remains of the gaps between the fin-shaped channel patterns **131** after the gate insulating layer **155** has been formed. In an example of this embodiment, the gate electrode **160** comprises a barrier metal layer **161** and a metal layer **163** stacked on the barrier metal layer **161**. The barrier metal layer **161** may be formed of a conductive material or a metal nitride material. For example, the barrier metal layer **161** may

include at least one of titanium nitride, tantalum nitride, tungsten nitride, hafnium nitride, and zirconium nitride. The metal layer **163** may be formed of at least one material having lower resistivity than the barrier metal layer **161**. For example, the metal layer **163** may include at least one material selected from the group consisting of tungsten, copper, hafnium, zirconium, titanium, tantalum, aluminum, ruthenium, palladium, platinum, cobalt, nickel, and conductive metal nitrides.

The semiconductor device may comprise an NMOS field effect transistor. In this case, the buffer pattern **121** may exert a tensile stress on the fin-shaped channel patterns **131**, i.e., the NMOS may have a tensile-strained channel. To this end, for example, the buffer pattern **121** may be formed of  $\text{Si}_{1-x}\text{Ge}_x$ , and the channel layer **130** may be formed of Si. Alternatively, the buffer pattern **121** may be formed of  $\text{Si}_{1-x}\text{Ge}_x$ , and the channel layer **130** may be formed of  $\text{Si}_{1-y}\text{Ge}_y$  (where  $x > y$ ). In still another example of an NMOS having a tensile-strained channel, the buffer pattern **121** may be formed of  $\text{In}_{1-x}\text{Ga}_x\text{As}$ , and the channel layer **130** may be formed of  $\text{In}_{1-y}\text{Ga}_y\text{As}$  (wherein  $x < y$ ).

The semiconductor device may also comprise a PMOS field effect transistor. In this case, the buffer pattern **121** may exert a compressive stress on the fin-shaped channel patterns **131**, i.e., the PMOS may have a compressive-strained channel. To this end, for example, the buffer pattern **121** may be formed of  $\text{Si}_{1-x}\text{Ge}_x$ , and the channel layer **130** may be formed of Ge. Alternatively, the buffer pattern **121** may be formed of  $\text{Si}_{1-z}\text{Ge}_z$ , and the channel layer **130** may be formed of  $\text{Si}_{1-w}\text{Ge}_w$  (wherein  $z < w$ ). In still another example of a PMOS having a compressive-strained channel, the buffer pattern **121** may be formed of  $\text{In}_{1-z}\text{Ga}_z\text{As}$ , and the channel layer **130** may be formed of  $\text{In}_{1-w}\text{Ga}_w\text{As}$  (wherein  $z > w$ ).

FIGS. **4** through **6** illustrate some other examples of a semiconductor device according to the inventive concept.

In the embodiment of FIGS. **2A-2G** and **3**, the buffer pattern **121** and the fins formed from the channel layer **230** constitute a channel-forming structure of a transistor.

According to the example shown in FIG. **4**, the channel layer **130** may be omitted such that the channel-forming structure of the transistor is constituted by only a buffer pattern.

More specifically, the semiconductor device of this example includes a buffer pattern **125** formed by performing an SEG process to form a buffer layer in the first trench **111**, forming a mask on the buffer layer, and etching the buffer layer using the mask as an etch mask to form the second trenches in the buffer layer. Each of the second trenches is narrower than the trench **111** in the insulating layer **110**. In addition, before the mask is formed, the epitaxially-grown buffer layer may be planarized until its top surface is coplanar with that of the insulating layer **110**, and the second trenches may be formed by anisotropically etching the planarized upper portion of the buffer layer.

Furthermore, in this example, as shown in FIG. **4**, the buffer pattern **125** includes a lower portion **125a** whose width is the same as the width **W1** of the first trench **111**, and a plurality of fin-shaped portions **125c** extending contiguously to and from the lower portion **125a** with each of the fin-shaped portions **125c** having a width **W2** smaller than the width **W1** of the first trench **111**. The top surfaces of the fin-shaped portions **125c** are disposed at a level higher than those of the insulating gap-filling pattern **143** and the recessed insulating layer **113**. Also, as described with reference to FIG. **2B**, the lower portion **125a** of the buffer pattern **125** has crystal defects, such as the threading dislocations **120d**, whereas the fin-shaped portions **125c** are of a mono-crystal-

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line semiconductor material which is substantially free of the crystal defects (e.g., threading dislocations **120d**).

More specifically, in the example of FIG. 4, the buffer pattern **125** is provided in the first trench **111** such that the lower portion **125a** of the buffer pattern **125** has the same first width **W1** as that trench **111**, and the buffer pattern **125** has a plurality of the fin-shaped portions **125c** extending from the lower portion **125a** and each of which has a second width **W2** smaller than the first width **W1**. The lower portion **125a** may have crystal defects (e.g., threading dislocations **125d**), which may be produced during the SEG process, whereas the fin-shaped portions **125c** are of substantially defect-free mono-crystalline semiconductor material. That is, in the buffer pattern **125**, the density of crystal defects is significantly higher in the lower portion **125a** than in the fin-shaped portions **125c**. In addition, the insulating gap-filling pattern **143** is interposed between the fin portions **125c** of the buffer pattern **125**, and the top surface of the insulating gap-filling pattern **143** is disposed at a level below that of the top surfaces of the fin portions **125c**.

In addition, in this example, gate electrode **160** extends across the fin-shaped portions **125c** of the buffer pattern **125**, and gate insulating layer **155** is interposed between the gate electrode **160** and the fin-shape portions **125c**.

In the example shown in FIG. 5, a plurality of the fin-shaped channel patterns **131** are provided on the buffer pattern **121**, and the distance between adjacent ones of the fin-shaped channel patterns **131** differs from the width of the insulating gap-filling pattern **143** interposed between a sidewall surface of the insulating layer **110** and the fin-shaped channel pattern **131** closest to the sidewall surface. In particular, in this example, the distance between adjacent ones of the fin-shaped channel patterns **131** is smaller than the width of the insulating gap-filling pattern **143** interposed between a sidewall surface of the insulating layer **110** and the fin-shaped channel pattern **131** closest to the sidewall surface.

According to still another example shown in FIG. 6, two or more fin-shaped channel patterns **131** are provided on the buffer pattern **121**. However, in this example, the width of the insulating gap-filling pattern **143** interposed between a sidewall surface of the insulating layer **110** and the fin-shaped channel pattern **131** closest to the sidewall surface is smaller than the distance between adjacent ones of the fin-shaped channel patterns **131**.

Another embodiment of a semiconductor device and a method of fabricating the same, according to the inventive concept, will now be described in detail with reference to FIG. 7 and FIGS. 8A through 8G.

Referring first to FIGS. 7 and 8A, a semiconductor substrate **100** includes a first region **10** and a second region **20**, and an NMOS field effect transistor is formed on the first region **10**, and a PMOS field effect transistor is formed on the second region **20**. An insulating layer **110** is disposed on the first and second regions **10** and **20** of the substrate **100**.

First trenches **111** are formed in the insulating layer **110** on the first and second regions **10** and **20**, respectively. The first trenches **111** may expose the semiconductor substrate **100**, and each of them may have a first width **W1** smaller than a thickness **H1** of the insulating layer **110**. Also, the width of the trench **111** on the first region **10** may be the same as different from the width of the trench **111** on the second region **20**. In any case, each of the first trenches **111** preferably have an aspect ratio (depth to width) ranging from about 1 to about 3, both inclusive. In a working example, the width **W1** of each first trench **111** ranges from about 50 nm to about 500 nm.

An SEG process may be performed to form buffer layers **120** in the first trenches **111**. The buffer layers **120** may be

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formed of a semiconductor material whose lattice constant is different from that of the semiconductor substrate **100**. For example, the buffer layers **120** may be formed of at least one material selected from the group consisting of Si, Ge, SiGe, and Group III-V semiconductor compounds.

The buffer layers **120** may be simultaneously formed on the first and second regions **10** and **20**. Alternatively, one of the buffer layers **120** may be formed on the first region **10**, and then, the other may be formed on the second region **20**. In this case, the buffer layers **120** on the first and second regions **10** and **20** may be different from each other in terms of lattice constant or composition (different ratios of elements in the same material), for example.

On each of the first and second regions **10** and **20**, as was described with reference to FIG. 2B, each of the buffer layers **120** has a lower portion **120a** with crystal defects and an upper portion **120b** which is substantially free of crystal defects. For example, most of the threading dislocations **120d** formed during the SEG process may be trapped or localized in a region below a specific height **H2** from the top surface of the semiconductor substrate **100**. That is, the density of the threading dislocations **120d** decreases in a vertical direction away from the semiconductor substrate **100**.

Also, each of the buffer layers **120** may be formed to fill a corresponding one of the first trenches **111**. Furthermore, the SEG process may be performed in an over-growth manner and in this case, the top surfaces of the buffer layers **120** are disposed above the level of the insulating layer **110**. Due to the difference in the rates at which the crystals grow in different crystal planes, the top surface of the buffer layer **120** may have facets, each of which lies in a plane extending at an acute angle relative to the top surface of the semiconductor substrate **100**. After the SEG process, the buffer layer **120** may be planarized until its top surface is coplanar with that of the insulating layer **110**.

Referring to FIGS. 7 and 8B, a first mask MP1 is formed on the second region **20** to cover one of the buffer layers **120**. Subsequently, the buffer layer **120** of the first region **10** exposed by the first mask MP1 is vertically recessed to form a first buffer pattern **121**. In the illustrated example, the height of the first buffer pattern **121** is smaller than the thickness **H1** of the insulating layer **110** and greater than the thickness, i.e., **H2**, of the lower portion of the buffer pattern **121**. Thus, the first buffer pattern **121** has a lower portion **121a** with crystal defects and an upper portion **121b** which is substantially free of crystal defects.

Next, a first channel layer **130** is formed on the first buffer pattern **121** to fill the first trench **111** on the first region **10**. The first channel layer **130** may be formed of a material whose energy band gap is different from that of the first buffer pattern **121**. For example, the first buffer pattern **121** may be formed of  $\text{Si}_{1-x}\text{Ge}_x$ , and the first channel layer **130** may be formed of Si. Alternatively, the first buffer pattern **121** may be formed of  $\text{Si}_{1-x}\text{Ge}_x$ , and the first channel layer **130** may be formed of  $\text{Si}_{1-y}\text{Ge}_y$  (wherein  $x > y$ ). In still another example, the first buffer pattern **121** may be formed of  $\text{In}_{1-x}\text{Ga}_x\text{As}$ , and the first channel layer **130** may be formed of  $\text{In}_{1-y}\text{Ga}_y\text{As}$  (wherein  $x < y$ ).

Also, the first channel layer **130** may be formed using an SEG process, and the first mask MP1 may be removed after the formation of the first channel layer **130**. Furthermore, the first channel layer **130** may be planarized so that the first channel layer **130** has a flat top surface.

Referring to FIGS. 7 and 8C, a second mask MP2 is formed on the first region **10** to cover the first channel layer **130**. Subsequently, the buffer layer **120** of the second region **20** exposed by the second mask MP2 is recessed to form a second

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buffer pattern 123. In the illustrated example, the height of the second buffer pattern 123 is smaller than the thickness H1 of the insulating layer 110 and greater than the thickness, i.e., H2, of the lower portion of the buffer pattern 121. Thus, the second buffer pattern 123 has a lower portion 123a with crystal defects and an upper portion 123b which is substantially free of crystal defects.

Next, a second channel layer 135 is formed on the second buffer pattern 123 to fill the first trench 111 on the second region 20. The second channel layer 135 may be formed of a material whose energy band gap is different from that of the second buffer pattern 123. Furthermore, the second channel layer 135 may be formed of a material different from the first channel layer 130. For example, the second buffer pattern 123 may be formed of  $\text{Si}_{1-x}\text{Ge}_x$ , and the second channel layer 135 may be formed of Ge. Alternatively, the second buffer pattern 123 may be formed of  $\text{Si}_{1-z}\text{Ge}_z$ , and the second channel layer 135 may be formed of  $\text{Si}_{1-w}\text{Ge}_w$  (wherein  $z < w$ ). In still another example, the second buffer pattern 123 may be formed of  $\text{In}_{1-z}\text{Ga}_z\text{As}$ , and the second channel layer 135 may be formed of  $\text{In}_{1-w}\text{Ga}_w\text{As}$  (wherein  $z > w$ ).

Also, the second channel layer 135 may be formed using an SEG process, and the second mask MP2 may be removed after the formation of the second channel layer 135. Furthermore, the second channel layer 135 may be planarized so that the second channel layer 135 has a flat top surface.

Referring to FIGS. 7 and 8D, the first channel layer 130 and the second channel layer 135 are patterned to form first fin-shaped channel patterns 131 and second fin-shaped channel patterns 137.

For example, the forming of the first fin-shaped channel patterns 131 and the second fin-shaped channel patterns 137 includes forming a mask 140 on the insulating layer 110 to expose portions of the first channel layer 130 and the second channel layer 135, and then, anisotropically etching the first channel layer 130 and the second channel layer 135 using the mask 140 as an etch mask to form second trenches 133. The second trenches 133 may be formed to expose part of the sidewall surface of the insulating layer 110. Also, the first and second buffer patterns 121 and 123 may be partially etched when the second trenches 133 are formed.

As a result, each of the second trenches 133 is narrower than the first trench 111 above which it is located. Therefore, the width W2 of each of the first fin-shaped channel patterns 131 is less than the width W1 of the first trench 111 in which the first fin-shaped channel patterns 131 are formed (corresponding to width of the lower portion 121a of the first buffer pattern 121). Similarly, the width W2 of each of the second fin-shaped channel patterns 137 is less than the width W1 of the first trench 111 in which the second fin-shaped channel patterns 137 are formed (corresponding to width of the lower portion 123a of the second buffer pattern 123).

Referring to FIG. 8E, insulating gap-filling layer 141 is formed to fill the second trenches 133. The insulating gap-filling layer 141 may be formed of an insulating material having a good gap-filling property, and the insulating gap-filling layer 141 may be formed of the same insulating material as the insulating layer 110. The insulating gap-filling layer 141 is preferably formed using a deposition process having a good step coverage property. After the deposition process has been performed, the insulating gap-filling layer 141 may be planarized to expose top surfaces of the first fin-shaped channel patterns 131 and the second fin-shaped channel patterns 137.

Referring to FIG. 8F, the insulating layer 110 and the insulating gap-filling layer 141 are etched back and thus, sidewall surfaces of the first fin-shaped channel patterns 131

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and the second fin-shaped channel patterns 137 are exposed. Accordingly, insulating gap-filling patterns 143 are formed between the first fin-shaped channel patterns 131 and between the second fin-shaped channel patterns 137. Also, the top surfaces of the recessed insulating layer 113 and the insulating gap-filling pattern 143 may be located at a level between those of the top and bottom surfaces of the first fin-shaped channel patterns 131 or the second fin-shaped channel patterns 137.

Referring to FIGS. 7 and 8G, first gate insulating layer 155a and first gate electrode 160a are sequentially formed on the first region 10 to cross the first fin-shaped channel patterns 131, and second gate insulating layer 155b and a second gate electrode 160b are sequentially formed on the second region 20 to cross the second fin-shaped channel patterns 137.

The first and second gate insulating layers 155a and 155b may be formed of a high-k dielectric (e.g., hafnium oxide, hafnium silicate, zirconium oxide, or zirconium silicate). The first and second gate electrodes 160a and 160b may also be formed to contain metallic materials whose work-functions are different from each other. The first gate electrode 160a may include a first barrier metal layer 161a and a first metal layer 163a, and the second gate electrode 160b may include a second barrier metal layer 161b and a second metal layer 163b.

The first and second barrier metal layers 161a and 161b may be formed of at least one metal nitride, for example, titanium nitride, tantalum nitride, tungsten nitride, hafnium nitride, or zirconium nitride. The first and second metal layers 163a and 163b may be formed of at least one material selected from the group consisting of tungsten, copper, hafnium, zirconium, titanium, tantalum, aluminum, ruthenium, palladium, platinum, cobalt, nickel, and conductive metal nitrides.

Furthermore, as shown in FIG. 7, first source and drain electrodes 153a may be formed at both sides of the first gate electrode 160a, and second source and drain electrodes 153b may be formed at both sides of the second gate electrode 160b.

FIG. 9 is a sectional view of still another example of a semiconductor device according to the inventive concept.

In the embodiment shown in FIG. 9, first buffer pattern 121 and first fin-shaped channel patterns 131 are formed on the first region 10, and second buffer pattern 125 is formed on the second region 20.

The lower portion 125a of the second buffer pattern 125 has the same width W1 as the trench 111 in which it is formed, and the second buffer pattern 125 has a plurality of fin-shaped portions 125c extending from the lower portion 125a. Each of the fin-shaped portions 125c has a width W2 smaller than the width W1. The fin-shaped portions 125c may be formed such that their top surfaces are substantially coplanar with those of the first fin-shaped channel patterns 131.

Furthermore, in this example, the first buffer pattern 121 and the second buffer pattern 125 may be formed of different materials. For example, the first buffer pattern 121 may be formed of a Group III-V compound semiconductor material, while the second buffer pattern 125 is formed of SiGe. Alternatively, the first buffer pattern 121 and the second buffer pattern 125 may be formed of the same materials/compounds, but in which the ratios of the elements that make up the materials/compounds are different from each other.

FIG. 10 illustrates an example of a CMOS inverter including a CMOS transistor according to the inventive concept.

Referring to FIG. 10, the CMOS inverter of this example includes a PMOS transistor P1 and an NMOS transistor N1. The PMOS and NMOS transistors P1 and N1 are connected in series between a driving voltage terminal Vdd and a ground



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voltage terminal  $V_{SS}$ , and an input signal IN may be inputted in common to the gates of the PMOS and NMOS transistors P1 and N1. An output signal OUT may be outputted in common from the drains of the PMOS and NMOS transistors P1 and N1. Also, a driving voltage  $V_{DD}$  is applied to the source of the PMOS transistor P1, and a ground voltage  $V_{SS}$  is applied to the source of the NMOS transistor. The CMOS inverter inverts the input signal IN and outputs the output signal OUT. In other words, when a logic level '1' is inputted as the inverter input signal IN, a logic level '0' may be outputted as the output signal OUT. On the other hand, when a logic level '0' is inputted as the inverter input signal IN, a logic level '1' is outputted as the output signal OUT.

FIG. 11 illustrates an example of an SRAM device including a CMOS transistor according to the inventive concept.

Referring to FIG. 11, in this example, each cell in the SRAM device includes first and second access transistors Q1 and Q2, first and second driving transistors Q3 and Q4, and first and second load transistors Q5 and Q6. Also, the sources of the first and second driving (pull-up) transistors Q3 and Q4 are connected to a ground line  $V_{SS}$ , and the sources of the first and second load transistors Q5 and Q6 are connected to a power line VDD.

The first driving transistor Q3 and the first load transistor Q5, which may be NMOS and PMOS transistors, may constitute a first inverter. Likewise, the second driving transistor Q4 and the second load transistor Q6, which may be NMOS and PMOS transistors, may constitute a second inverter.

The output terminals of the first and second inverters are connected to the sources of the first and second access transistors Q1 and Q2. Also, the input terminal of the first inverter and the output terminal of the second inverter are connected and conversely the input terminal of the second inverter and the output terminal of the first inverter are connected, to constitute a latch circuit. The drains of the first and second access transistors Q1 and Q2 may be connected to first and second bit lines BL and /BL, respectively.

FIG. 12 illustrates an example of an electronic system including a semiconductor device according to the inventive concept.

The electronic system may be that of an electronic product such as a personal digital assistant (PDA), a portable computer, a web tablet, a wireless phone, a mobile phone, a digital music player, a memory card, or the like. Such electronic products may receive or transmit information or data by wireless.

Referring to FIG. 12, the electronic system 1100 of this example includes a controller 1110, an input-output (I/O) unit 1120, a memory device 1130, an interface 1140, and a bus 1150 serving as a pathway for data communication. The controller 1110, the input-output unit 1120, the memory device 1130 and/or the interface 1140 may be connected or coupled to each other via the bus 1150. At least one of the controller 1110, the input-output unit 1120, the memory device 1130, and/or the interface 1140 includes a semiconductor device according to the inventive concept.

The controller 1110 may include at least one of a microprocessor, a digital signal processor, a microcontroller, or similar logic device. The input-output unit 1120 may include a keypad, keyboard, a display device, or the like.

The memory device 1130 may be configured to store data and/or commands. The interface unit 1140 may transmit electrical data to a communications network or may receive electrical data from a communications network.

The interface unit 1140 may operate by wireless or cable. For example, the interface unit 1140 may include an antenna for wireless communications or a transceiver for cable communications. Although not shown in the drawings, the elec-

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tronic system 1100 may further include a fast DRAM device and/or a fast SRAM device, which may serve as a cache memory for improving an operation of the controller 1110.

According to the inventive concept as described above, a semiconductor pattern is formed in a trench dimensioned such that crystal defects are trapped or localized in a lower portion of the semiconductor pattern. Accordingly, an upper portion of the semiconductor pattern is formed without crystal defects. The upper portion of the semiconductor pattern is patterned to form a plurality of fins, each of which is narrower than the lower portion of the semiconductor pattern. This makes it possible to realize fin field effect transistor with high density and improved characteristics.

Finally, embodiments of the inventive concept and examples thereof have been described above in detail. The inventive concept may, however, be embodied in many different forms and should not be construed as being limited to the embodiments described above. Rather, these embodiments were described so that this disclosure is thorough and complete, and fully conveys the inventive concept to those skilled in the art. Thus, the true spirit and scope of the inventive concept is not limited by the embodiment and examples described above but by the following claims.

What is claimed is:

1. A semiconductor device comprising:

a substrate;

an insulating layer disposed on the substrate and having a trench exposing a surface portion of the substrate;

a channel-forming structure comprising crystalline semiconductor material, the channel-forming structure having a lower portion located in the trench and fins extending upright on the lower portion, wherein the fins are spaced from each other and are each narrower than an opening of the trench, and the lower portion of the channel-forming structure has a higher crystal defect density than the fins of the channel-forming structure.

2. The semiconductor device of claim 1, wherein the fins are devoid of crystal defects.

3. The semiconductor device of claim 1, wherein the fins extend along a length of the trench, are spaced from each other in a widthwise direction of the trench, and are each narrower than the trench in the widthwise direction.

4. The semiconductor device of claim 1, wherein the fins extend upward beyond the opening of the trench.

5. The semiconductor device of claim 1, wherein the crystal defect density in the lower portion of the channel-forming structure increases in a depth direction of the trench.

6. The semiconductor device of claim 1, wherein the fins include respective buffer patterns which are a unitary part of the lower portion of the channel-forming structure, and fin-shaped channel patterns on the respective buffer patterns, the buffer patterns and the fin-shaped channel patterns having different energy band gaps.

7. The semiconductor device of claim 6, wherein the fin-shaped channel patterns comprise a material selected from the group consisting of Ge, SiGe, and a Group III-V semiconductor compound.

8. The semiconductor device of claim 6, wherein the buffer patterns and the fin-shaped channel patterns are formed of Group III-V semiconductor compounds having respectively different energy band gaps.

9. The semiconductor device of claim 1, wherein the channel-forming structure is a unitary body of semiconductor material.

10. The semiconductor device of claim 9, wherein the semiconductor material is selected from the group consisting of Ge, SiGe, and a Group III-V semiconductor compound.

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11. The semiconductor device of claim 3, wherein a depth-to-width aspect ratio of the trench is between 1:1 and 3:1 both inclusive.

12. The semiconductor device of claim 11, wherein the width of the trench is at least 50 nm.

13. The semiconductor device of claim 3, further comprising a gate electrode extending longitudinally across the fins in the widthwise direction of the trench, a gate insulating layer interposed between the gate electrode and the fins, and source/drain regions in the trench at opposite ends of the fins.

14. A semiconductor device comprising:

a semiconductor substrate;

an insulating layer disposed on the substrate and having a trench exposing a surface portion of the substrate, wherein a depth-to-width aspect ratio of the trench is between 1:1 and 3:1 both inclusive; and

a crystalline channel-forming structure disposed in the trench, the crystalline channel-forming structure having an epitaxial lower portion disposed on the surface portion of the semiconductor substrate and occupying a bottom portion of the trench, and epitaxial fins extending upright on the lower portion,

wherein the epitaxial fins are spaced from each other in a widthwise direction of the trench and are each narrower than the trench in the widthwise direction.

15. The semiconductor device of claim 14, wherein the width of the trench is at least 50 nm.

16. The semiconductor device of claim 15, wherein the epitaxial fins include respective buffer patterns which are a unitary part of the epitaxial lower portion of the crystalline channel-forming structure, and fin-shaped epitaxial channel patterns on the respective buffer patterns, the buffer patterns and the fin-shaped channel patterns having different energy band gaps.

17. The semiconductor device of claim 16, wherein the buffer pattern and the fin-shaped channel patterns are formed of Group III-V semiconductor compounds having respectively different energy band gaps.

18. The semiconductor device of claim 14, further comprising a gate electrode extending longitudinally across the epitaxial fins in the widthwise direction of the trench, a gate insulating layer interposed between the gate electrode and the epitaxial fins, and source/drain regions in the trench at opposite ends of the epitaxial fins.

19. A semiconductor device comprising:

a substrate;

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an insulating layer disposed on the substrate and having a first trench exposing a first surface portion of the substrate and a second trench exposing a second surface portion of the substrate;

a first channel-forming structure comprising crystalline semiconductor material, the first channel-forming structure having a first lower portion located in the first trench and first fins extending upright on the first lower portion, wherein the first fins are of a first conductivity type, are spaced from each other and are each narrower than an opening of the first trench, and wherein the first lower portion of the first channel-forming structure has a higher crystal defect density than the first fins of the first channel-forming structure; and

a second channel-forming structure comprising crystalline semiconductor material, the second channel-forming structure having a second lower portion located in the second trench and second fins extending upright on the second lower portion, wherein the second fins are of a second conductivity type, are spaced from each other and are each narrower than an opening of the second trench, and wherein the second lower portion of the second channel-forming structure has a higher crystal defect density than the second fins of the second channel-forming structure.

20. The semiconductor device of claim 19, further comprising:

a first gate electrode extending longitudinally across the first fins in a widthwise direction of the first trench, a first gate insulating layer interposed between the first gate electrode and the first fins, and first source/drain regions in the first trench at opposite ends of the first fins, wherein the first fins, the first gate electrode, the first gate insulating layer, and the first source/drain regions constitute a PMOS transistor; and

a second gate electrode extending longitudinally across the second fins in a widthwise direction of the second trench, a second gate insulating layer interposed between the second gate electrode and the second fins, and second source/drain regions in the second trench at opposite ends of the second fins, wherein the second fins, the second gate electrode, the second gate insulating layer, and the second source/drain regions constitute a NMOS transistor;

wherein the PMOS transistor and the NMOS transistor are connected in a CMOS configuration.

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